

During his eight month stay at Colorado Springs Tesla carried out a series of experiments with his spark-discharge oscillator. From the results obtained he came to the conclusion that the waves of his provisory transmitter spread through earth as concentric circles with the ground plate of the oscillator at the center and, accordingly, their intensity decreases linearly with the distance and not in proportion to the square of distance like the Hertzian waves. He became aware of the possibility of producing stationary waves of certain exactly defined wave-lengths. In September 1899 he succeeded in lighting a lamp of approximately 10 W "placed far out into the field," the exact distance from the ground plate being indicated in the Colorado Springs Notes, in the introductory comment for that month. Encouraged by these results he probably at that time began to consider the construction of a similar but more powerful transmitter which would not only enable reception of its telegraphic signals throughout the world but also the wireless transfer of power required for operation of industrial plants.

After his return to New York in January 1900 he began looking for a financier interested in the realization of such a venture. At the end of November 1900 he established the first contact with J. P. Morgan, the famous financial magnate, and on March 1, 1901 signed a letter of agreement that seemed to him extremely favorable for the realization of his aim in life. For \$150,000, which was a great sum of money at that time, he sold to Morgan 51% of interest in all the patents "having relation to or being useful in any way in connection with electric lighting and wireless telegraphy or telephony" already issued to him and to be secured by him later on, "for putting his discoveries and inventions into practical use."

At that time, immediately before signing the agreement and several months later on, Tesla continued rewriting some of his Colorado notes. Apart from this, in his laboratory in New York he performed a series of additional experiments in order to ascertain the effect of arrangement of coils in the oscillatory circuit on the inductivity and tuning. Reconsidering the phenomenon of stationary waves he came to a significant conclusion that the waves of his transmitter will be most effectively received at the opposite point of the terrestrial globe. He analyzed the feasibility of wireless transfer of energy to great distances not only with a view of sending Morse code but also with the intention to transmit printed text and images. He considered all of that to be attainable by his spark-discharge oscillator, however with some additional devices and improvements.

In the analysis of the possibility of wireless transfer of energy in the quantities and rates required for industrial purposes his estimates were very conservative. Finally, he ascertained that it could be feasible only by a successful use of resonant effects.

A general conclusion drawn from all these considerations was that for the attainment of this goal a powerful "magnifying transmitter" would be required, the terminal of which could be operated at extremely high tensions of several million volts. Aware of the fact that such a terminal would be the most expensive part of the transmitter, i.e. of the whole project, he considered various possibilities relating to its height (from 60 to 200 m approximately) and optimal geometry of its top. It is interesting to follow the development of the idea of the famous tower on Long Island through preserved calculations of capacitances and inductances and of the maximum possible tension at the top of the terminal and sketches of various hemispheres and spherical segments with toroidal appends.

* In the preparation of these notes for publishing only a few orthographic errors (e.g. *chocking* instead of *choking*) as well as the units for capacitance (c.m. and M.F. instead of cm and μ F resp.), which could cause some ambiguities, have been corrected. Other errors have been retained.

All these considerations can be traced through these notes kept in New York, for the most part from May to August 1901. Some of them are arranged like the Colorado Springs Notes, as if he had intended to publish them at a proper time. The majority of them, however, are hardly legible drafts with orthographic errors* and lapses in usual arithmetic operations as if they had been written in great haste, just to keep in mind a new idea deserving further elaboration.

Despite their imperfectness these notes are significant for the history of science. Together with the preserved documents from Long Island i.e. from Wardencliff, they will surely contribute to better and more complete comprehension of Tesla's greatest, though unfinished project.

Milan Ćirić, PhD

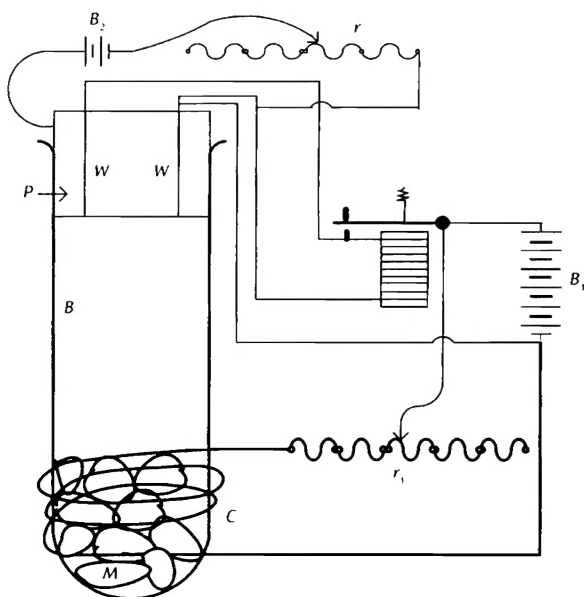
Aug. 4, 1899

Sensitive receiver for detecting feeble disturbances

This device is based on a principle briefly described on a previous occasion which formed the subject of experiments about two years ago. Pressing work prevented further investigation but I was convinced that a good device possessing certain advantages over those usually employed may be developed on this principle. Work is now to be resumed and plan outlined below is to be adopted.

Referring to the diagram B is a bottle containing volatilisable or evaporable (easily) material M closed by a plug P through which pass the wires $w w$. The two wires are connected to a battery B_2 in series with an adjustable resistance r . To the wires is also connected a relay R of extremely *high resistance*.

By means of an adjustable resistance r_1 that is connected in series with a coil C surrounding the bottle, to an other stronger battery B_1 , the current of the latter through the convolutions of coil C may be so graduated that the material M is evaporated or volatilised at the required rate. Now the material is such that a minute film of it deposited between wires $w w$ will make a path of a high resistance, but sufficiently low to shunt the relay more or less. When this film is deposited, the resistance r is so adjusted that the relay is just balanced.



Sept. 5, 1899
From old notebook
Colorado Springs

The large ball was elevated until the secondary of oscillator was in resonance with the primary there being 7 turns on each side and 13 turns of Regulator in the primary circuit.

An old coil was taken and its vibration determined. The coil was wound in one layer with two kinds of wire: Wire № 22 about $\frac{3}{5}$ of the layer from one end; wire № 18 the rest of the layer. The drum was $25\frac{1}{4}$ " diam. When connected with the thick wire to the ground with this wire free resonance was obtained with 6 turns on each side and 7 turns of Regulator; when turned upside down, that is, with the thin wire connected to the ground and the thick free, resonance was with 6 turns on each side and 10 turns of Regulator in circuit. In the former case, when the coil was connected to the water main about 300 feet away from the shop it gave a 3" spark to the body of an assistant; when turned the other way spark was much smaller but thicker. Experience shows that in coils for receiving the last turns should be of thinner wire. The receiving circuit should be in fact thickest on ground connection and the conductor ought to taper down towards the free end. The section at any point may be calculated from data which give the current. A telephone connected in shunt gives strong sound when a wire added to the free terminal and placed in a certain position, so as to slow down the vibration and bring it in resonance with the secondary system of oscillator in shop. The sound in the telephone was chiefly due to the low frequency break – about 3000 per second but a very high note was barely audible between the breaks. The sound in the telephone ceased as soon as wire was slightly displaced and resonating condition disturbed.

Note: no spark in secondary oscillating system.

Sept. 7, 1899
From old notebook
Colorado Springs

The wire № 22 on coil experimented with on Sept. 5, was taken down and wire Nr. 18 wound up. The total number of turns was now 495. The secondary oscillatory system was used as before and the coil was connected to the water pipe with one end the other end free straight up. In the succeeding test turns were gradually cut off from the bottom. Spark length was noted in the way described.

Results:

Number of turns	Spark to body no capacity on terminal	Spark with small terminal sphere
495	$\frac{3}{8}$ "	smaller
470	$\frac{7}{16}$ "	"
460	$\frac{7}{16} + \frac{1}{64}$ "	"
450	$\frac{7}{16} + \frac{1}{37}$ "	"
440	$\frac{9}{16}$ "	almost same
435	shade more	rather less
430	almost $\frac{11}{16}$ "	$\frac{1}{2}$ "
425	$\frac{3}{4}$ "	$\frac{1}{2}$ "
420	$\frac{3}{4}$ " full	"
415	$\frac{7}{8}$ "	"
410	1"	$\frac{9}{16}$ "

Number of turns	Spark to body no capacity on terminal	Spark with small terminal sphere
405	1 $\frac{3}{16}$ "	$\frac{5}{8}$ "
400	1 $\frac{1}{4}$ "	$\frac{5}{8}$ "
395	1 $\frac{1}{4}$ "	$\frac{5}{8}$ " full
390	1 $\frac{1}{4}$ "	$\frac{5}{8}$ "
385	"	"

By further reduction of turns the spark continuously diminished. The true tone was obtained with from 85 – 400 turns. The experiment shows bad effect of coils of comparatively large diameter. It also shows increase of effect of wire № 18 over wire № 22. It is evident that small resistance, great self-induction small capacity are the requirements for sharp and strong response in these circuits.

June 2, 1900

Note about method of insulating conditions by freezing:

Insulating effected by cooling $\left\{ \begin{array}{l} \text{both ways} \\ \text{one way} \end{array} \right\}$ in conductor

Continuously maintaining frozen

Insulating and fastening?

Continuously maintaining fastened

Diminution of resistance considered

Cheap conductors to consider

Heat supplied at rate computed

Cooling agents {gas, fluid liquid}

Special care when air is used

Special provision for desiccating?

Conveyance of material to be utilized individually

Iron as sheet metal considered

Consideration as to pressure and temperature, curves

Chart of curves including all considerations and showing most economical relations of all.

Utilization of river beds, channels natural or artificial

Underground and deep sea conditions specially considered

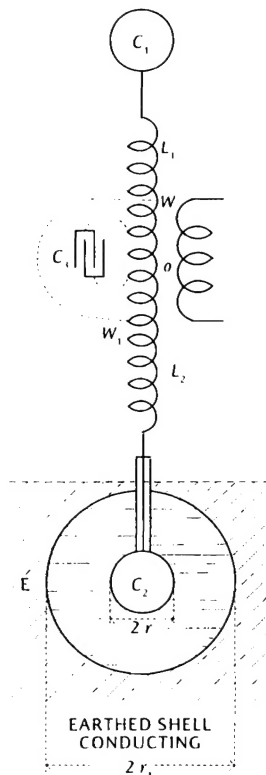
Particular case of insulating in places, the rest of conductor being otherwise protected as by air.

Plans and designs special cases: Niagara

July 23, 1900
From old notes

In my system of transmission through Earth by conduction for exciting tuned circuits the maximum pressure should be at C_1 . This is always the case when the length of conductor from ground to loop is $\frac{1}{4}\lambda$ or $\frac{n}{4}\lambda$, n being uneven number. But the condition may be satisfied also by making the conductor $\frac{1}{2}\lambda$ or an even number of wavelengths. This can be done by arrangement illustrated when $C_1 = C_2$, it being understood that C_1 is the capacity of the sphere or terminal C , while the capacity of C_2 is taken with reference to the conducting enclosure* E . Expressed in symbols, $C_2 = K \frac{r r_1}{r_1 - r} = C_1$.

* Inclosure in the manuscript - Ed.



If we use oil K will be about $= 2$. The same arrangement lends itself also to greater lengths of wire than $\frac{1}{2}$ wave for evidently so long as the capacities are equal the system will have the neutral point in middle as in ordinary coil and the potentials on top and bottom will be both respectively plus and minus maximum.

The conductor $L_1 L_2$ may be excited in any way as through primary P . A condenser C_1 may be advantageously employed to shunt. The more the capacity C_2 gets preponderating over C_1 the more the neutral point o will shift lower and finally when C_2 practically infinite then the vibration will be one half as fast and the conductor $L_1 L_2$ will be $\frac{\lambda}{4}$ or $\frac{n}{4}\lambda$ as explained above. The adjustment can be made by taking two points connecting and shifting up and down along $L_1 L_2$. There will be a maximum in middle position ww_1 . With fine spark gap to Earth also easy to investigate. No sparking at neutral point.

Aug. 5, 1900

1 lb. water 1°C, 1390 ft lbs

To carry 1 H.P. we have $\frac{33000}{1390} = 24$ lb (about) 1°C.

Now 1 lbs. air has specific heat in ratio $\frac{23}{100}$ smaller hence we want for carrying 1 H.P. $\frac{100}{23} \cdot 24$ lbs air 1°C.

If the air be - 200° less than in closure we have $\frac{100}{23} \cdot \frac{24}{100} = \frac{12}{23} = 0.52$ lbs. for each H.P. to carry off.

Now 1 lbs. of water is $\frac{1}{62}$ of a cub. foot.

Since air is 776 times lighter we shall have $\frac{776}{62} = 12.5$ cub. feet per lb. or 0.52 lbs of air will have volume of $0.52 \times 12.5 = 6.5$ cub. feet.

But as air is 200° colder its volume for the above weight will be much less about $6.5 \left(1 - \frac{200}{273}\right) = 6.5 \times 0.27 = 1.755$ cub. feet.

This will carry off 1 H.P. (per minute). Therefore to carry off at the rate of 1 H.P. we have $\frac{1.755}{60} = 0.03$ lbs cub. feet (nearly) per second.

Assume hollow pipe 1" square. There would go through this pipe at the velocity of feet per sec. a volume of $12v$ cub. inches or $\frac{12v}{1728}$ cub. feet. Hence $\frac{12}{1728} \cdot v = 0.03$ this gives for $v = 144 \times 0.03 = 4.32$ feet.

Otherwise stated we want to carry off 1 H.P. in velocity of 4.32 feet per second in a pipe of 1 square inch section with air. Now it is easy to have 1000 feet. This would be competent to carry off $\frac{1000}{4.32} = 230$ H.P. with return pipe 460 H.P.

If same copper used loss in Buffalo would be 1/5 of 20% that is 4%. Therefore total power 11500 H.P.!

O.K.

Sept. 3, 1900

According to Hensel's 162 gram Cellulose require 176 Litres CO₂ and 352 Litres oxygen free furthermore 100 grams leaves ... 1 Litre N.

From this take for instance a tree of ordinary size. The weight may be 4000 lbs. = $4000 \times 450 = 1\,800\,000$ grams approx. This tree will take up more than $\frac{1800000}{162} \cdot 176 = 1900000$ librae CO₂ and will give off more than 3,8000000 librae O. Not to speak of the N of the leaves. A square mile may have 10000 trees. This would want 19,000,000,000 CO₂ and free 38,000,000,000 Litres O!

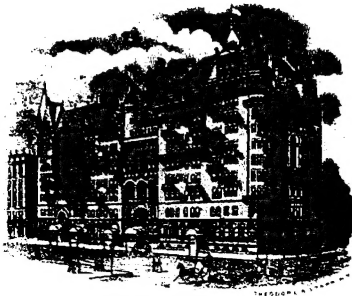
1 cub. foot has about 60 librae this would make $\frac{19000000000}{60} = 300,000,000$ cub. feet CO₂ bound and 600,000,000 cub. feet O.

A cubic mile has roughly 5300×5300 cub. feet hence $\frac{600000000}{53 \times 53 \times 53 \times 10^6} = \frac{600}{53 \times 53 \times 53} = \frac{6}{1489}$ cub. miles of oxygen free and $\frac{3}{1489}$ cub. CO₂ bound for every mile square of forest. Or 496 square mile forest binds one cub. mile of CO₂ and free 2 cub. miles Oxygen.

Say roughly

1000 square mile forest binds 2 cub. miles of CO₂ and free 4 cub. m. O.

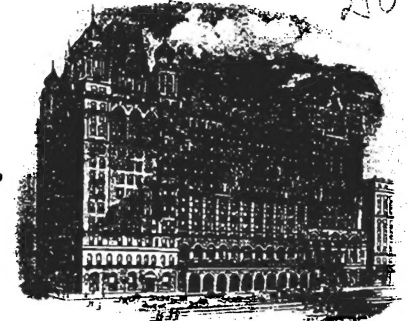
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THE ASTORIA

New York July 23 1900

from old note



In any system of transmission through earth by conduction for exciting tuning circuits the maximum pressure should be at C_1 . This is always the case when the length of conductor from ground to top is $\frac{1}{4}\lambda$ or $\frac{3}{4}\lambda$ & being uneven number. That the condition may be satisfied also by making the conductor $\frac{1}{2}\lambda$ or an even number of wavelengths. This can be done by arrangement of inductances. Then can be done by inductances that inductance when $C_1 = C_2$ & being inductance that C_1 is the capacity of the sphere or terminal C_1 while the capacity of C_2 is taken with reference to the conducting inductance E . Expressed in symbols

$$C_2 = K \cdot \frac{r r_1}{r_1 - r} C_1 \text{ If } r \text{ is in air } K \text{ will be about } = 2$$

The same arrangement lends itself also to greater lengths of wire than the same for evidently as long as the capacities are equal the system will have the neutral point in the middle as an ordinary coil and the potentials on top and bottom will be both respectively plus and minus maximum. The conductor L_1 may be excited in any way as through primary P . A condenser C_1 may be advantageously employed to tune. The more the capacity C_2 gets proportionally over C_1 the more the neutral point will shift lower and finally when C_2 practically infinite then the vibration will be one half as fast and the conductor L_1 will be $\frac{1}{4}\lambda$ or $\frac{3}{4}\lambda$ as explained above. The adjustment can be made by taking two points connecting and shifting up and down along L_1 . There will be a maximum in middle position or a high frequency spark gap to earth also easy to investigate. the operating as neutral point

Nov. 24, 1900

459

Consider Earth as straight conductor of length $l = 8000$ miles and mean diameter $r = 4000$ miles. That is $l = 5280 \times 8000 \times 12 \times 2.54 = 1278 \times 10^6$ cm.

$r =$ accordingly $r = 639 \times 10^6$ cm. This would give for inductance of Earth

$$L = 2 \times 1278 \times 10^6 [\log_e 4 - 0.75] = 2 \times 1278 \times 10^6 \times 0.6363$$

$$L = 1.63 \text{ Henry}$$

Capacity say $710 \mu\text{F}$.

$$\text{Hence period roughly } T = \frac{2\pi}{1000} \sqrt{1.63 \times \frac{700}{9 \times 10^5}}$$

$$T = \frac{6,28 \times 10.7}{3 \times 10^5} = 0.00022 \text{ roughly.}$$

That is to say the Earth will vibrate 454 times per sec.

$$\text{The wave would be } \frac{186000}{454} = 410 \text{ miles.}$$

Nov. 28, 1900

Take one of the experiments in Colorado with a comparatively small movement. A sphere 20 sq. feet surface is charged to a pressure of 3 million Volts. Say the wavelength is 4 miles. That means the half 2 miles. The density if uniformly distributed would be reduced in the ratio $\frac{20}{x}$ where x is the area of a cut out circle 2 miles wide. Suppose this circle to progress up to the equator it would be cylindrical and x would be

$$X = 2\pi D \text{ sq. miles} \quad D = 8000 \text{ miles}$$

$$= 6.28 \times 8000 = 6280 \times 8 = 50240.$$

Roughly say $X = 50000$ sq. miles or say

$$50000 \times 30\,000\,000 \text{ sq. feet.}$$

(over)

Hence the density would be $\frac{20}{15 \times 10^{11}} = \frac{2}{15 \times 10^{10}}$ smaller than on sphere. Since pressure and density are proportionate this would mean that the portion of ground would be charged to a pressure of $\frac{2 \times 3 \times 10^6}{15 \times 10^{10}} = \frac{6}{15 \times 10^4}$ Volts.

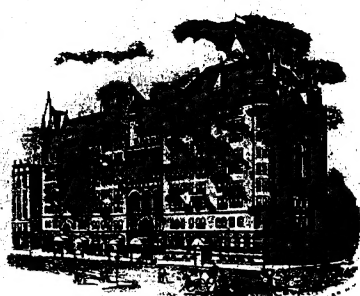
$$\text{The maximum will be about } \frac{3}{2} \times \frac{6}{15 \times 10^4} = \frac{9}{15 \times 10^4} = \frac{3}{5 \times 10^4} \text{ Volts.}$$

If a synchronized circuit be placed with a magnifying factor of 10^6 (which is easy) we would be able to charge a sphere like the one on the sending station with a pressure of $\frac{3}{5}$ Volt.

Capacity is say 40 cm. Energy would be per charge

$$\frac{1}{2} \times \frac{9}{25} \times \frac{40}{9 \times 10^{11}} = \frac{1}{50} \times \frac{40}{10^{11}} = \frac{4}{5 \times 10^{11}} \text{ Watts.}$$

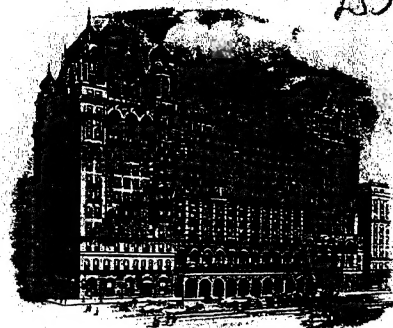
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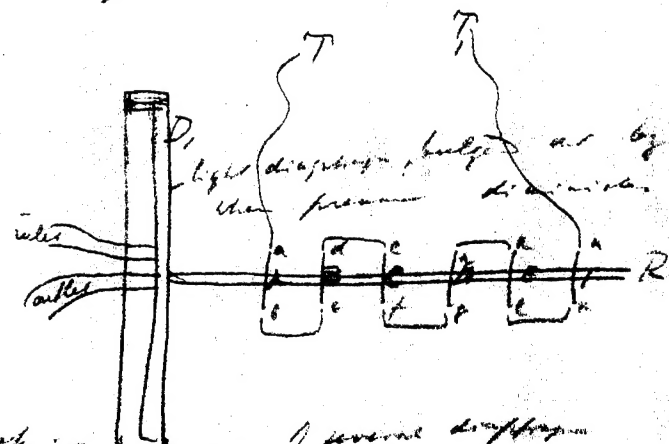


THE ASTORIA



New York Nov 24 1900

Method for controlling waves of great
intensity by waves or impulses of small intensity.



light diaphragm, bulged as by pressure slightly collapsing,
then pressure diminishes.
a - 2 small gaps through
which are discharge
planes
A - F sides of aluminum
or plates (any other metal),
very light preferable
on insulating rod R

Note: This arrangement of several droppers
or dropper strokes.
XXXX HHH

particular to dropper D,

The diaphragm D₁ is vibrated by controlling inlet of fluid
(air) and pressure or controlling the outlet. Then
small vibrations of diaphragm are multiplied when
all gaps a' selves and great variations in current P.P. are
observed.
P.S. Pressure may be on both sides
of diaphragm. Differences in
control of both spaces.

This is very good

Now with 100,000 charges per sec we have total energy movement $\frac{10^5 \times 4}{5 \times 10^{11}} = \frac{4}{5 \times 10^6}$ Watts. But this can be in the most intense action of Colorado apparatus $\frac{4}{5 \times 10^5}$ Watts.

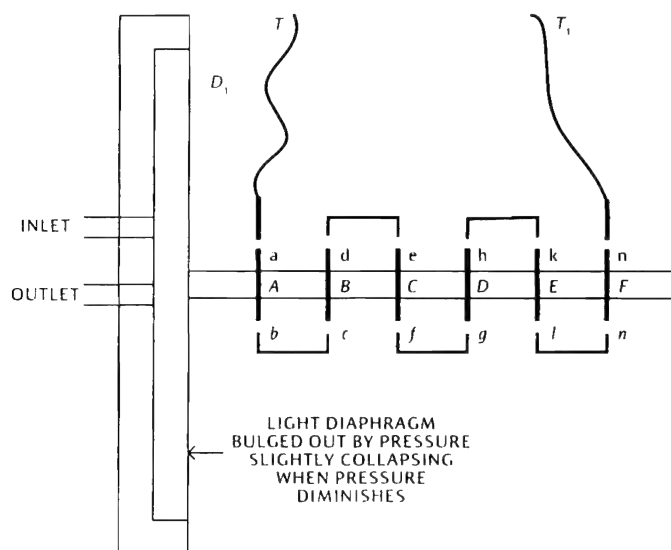
Note. As observed in Colorado Experiments the effect on the opposite side of Earth will be much stronger, hence with plate or roof on building and capacity a little over 100 meter diam. we would get about 200 times that is $\frac{4 \times 200}{5 \times 10^6} = \frac{8}{5 \times 10^4}$ Watts which is far more than necessary.

P.S. Increase sphere or capacity 2000 times we have $\frac{4}{5 \times 10^6} \times 2 \times 10^3 = \frac{8}{5 \times 10^2}$ roughly $\frac{1}{50}$ Watt perfectly sufficient. In the* more easy.

* Illegible

Means and method for controlling waves of great intensity by waves or impulses of small intensity

Light diaphragm, bulged out by pressure, slightly collapsing when pressure diminishes



Note. This arrangement of several diaphragms to lengthen stroke.

a - *n* small gaps through which arc discharge passes. *A* – *F* wires of aluminium or plates (any other metal). Very light, preferably on insulating rod *R* fastened to diaphragm *D*₁

The diaphragm D_1 is vibrated by controlling inlet of fluid (air) under pressure or controlling the outlet. The small vibrations of diaphragm are multiplied since all gaps in series and great variations in circuit TT_1 are obtained.

P.S. Pressure may be on both sides of diaphragm. Differential control of **both** spaces. This is very good.

How much capacity is it practicable to use? A wire about 200 feet high will have say 300 cm. Hence to have 300 000 we have 1000 such wires!

Jan. 24, 1901

Motor windings for new oscillator light plant small, 2 mica condensers, primary with secondary winding about 300 V on latter. Break mercury on mercury.

Take wire N^o 19 as before calculated we shall have 24 turns per inch, on little core 1 $\frac{5}{8}$ " clear, 39 turns per layer. This allowing for paper between layers will give 10 layers. Space clear is $\frac{5}{8}$ ". Consequently we shall have total $39 \times 10 \times 2 = 780$ turns.

We have assumed before 10,000 lines per sq. cm. Now determine Ampere-turns on armature. Now length of conductor is as follows:

1 conductor 1" or 2.54 cm. Call N number of turns. We shall have sizes of 18 holes, 4 holes are not included on each side seven holes. Say that x is number of turns in each hole we shall have total $7 \times x$. Total length of active conductor: 7×2.54 cm.

Velocity v will be as follows:

Mean diam. 47 cm. 2400 per minute gives 40 per second or $47 \times 40 = 1880$ cm per sec = v .

We shall have now e.m.f. counter on motor for that speed:

Now we shall have in air lines as follows.

Sect. of armature total is 8.875 sq. cm. Section of air gap total 47.60 cm sq. As there are 10000 lines per sq. cm in armature there will be through the air per sq. cm $\frac{8.875}{47.60} 10000$, or per sq. cm 1864 lines.

$$\text{Hence } E = 220 \times 10^8 = 7x \times 2.54 \times 1864 \times 1880;$$

$$x = \frac{22 \times 10^9}{17.78 \times 1864 \times 1880} = \frac{22 \times 10^9}{623 \times 10^4} = \frac{22 \times 10^4}{623} = 353 \text{ turns.}$$

* Illegible

Conclusion: wind ten layers N^o 19 wire * series

Arm. $\left\{ \begin{array}{l} \text{N}^{\circ} 24 \text{ if possible} \\ \text{N}^{\circ} 26 \text{ probably} \end{array} \right\}$

Second estimate lees

Take 12 layers N^o 20 wire about 43 turns on layer

Arm. N^o 26 wire turns in each groove: 300 turns.

Approximate theoretical estimate of constant determining wavelength of electrical disturbance through Earth

Taking Clarke spheroid of 1878 the average radius of Earth is:

$$\left. \begin{array}{l} 6,378,301 \text{ Equatorial} \\ 6,356,515 \text{ polar} \\ \hline 12,734,816 : 2 = \end{array} \right\} \text{average radius } r = 636740000 \text{ cm}$$

This may be adopted as the electrostatic capacity or in farads:

$$\frac{63674 \times 10^4}{9 \times 10^{11}} = \frac{63674}{9 \times 10^7} = \frac{7075}{10^7} = 0.0007075 \text{ farad.}$$

In miles, being convenient to calculate in larger numbers,

$$\left. \begin{array}{l} \text{equatorial radius is } 3963.296 \text{ miles} \\ \text{polar} \quad \quad \quad 3950.738 \text{ " } \end{array} \right\} \text{average radius } 3957 \text{ miles approx.}$$

The diameter is thus 7914 miles.

Let us now suppose that there would be n waves, then the Earth's surface will be divided in $2n$ parts and the average capacity of each part will be $\frac{1}{2n}$ th of the whole capacity of the globe. Similarly the inductance of each part on the average may be assumed to be $\frac{1}{2n}$ th of the whole inductance.

Determination of approximate inductance and capacity per mile.

For the present purposes it will be sufficient to consider the Earth as a cylindrical conductor of same capacity. Call R capacity of the globe = r . The capacity of cylindrical conductor of same length would be $\frac{l}{2 \log_e \frac{l}{r_1}} = r$. Now $l = 2r$. Hence $\frac{2r}{2 \log_e \frac{l}{r_1}} = r$, or $\log_e \frac{l}{r_1} = 1$ or $\text{nat log} \times 2.3025851 = 1$, $\log \frac{l}{r_1} = \frac{1}{2.3025851} = 0.43429$. Hence $\frac{l}{r_1} = 2.72$ approx. $r_1 = \frac{2r}{2.72} = \text{approx. } 2910 \text{ miles} = r_1$. A cylinder of

same length as Earth and radius about 2910 miles would have same capacity.

Inductance of cylinder of such dimensions should be ignoring magnetic influence (considering $\mu = 1$)

$$L = 2l \left(\log_e \frac{2l}{r_1} - 0.75 \right) \frac{2l}{r_1} = 5.44$$

$$\log_e \frac{2l}{r_1} = 1.69378$$

$$L = 2 \times 2 \times 63674 \times 10^4 (1.69378 - 0.75) = 4 \times 63674 \times 9437.8 = 2,403,770,000 \text{ cm}$$

$$\text{or } L = 2.40377 \text{ Henry.}$$

To sum up: Capacity of cylinder 0.0007075 farad

Inductance " 2.40377 Henry

Note. The Earth being magnetic this inductance will be no doubt greater. This is to be followed up.

Now average inductance and capacity per mile will be

$$\text{Capacity per mile } \frac{0.0007075}{7914} = C$$

$$\text{Inductance per mile } \frac{2.40377}{7914} = L$$

For vanishing resistance we have $\alpha = p\sqrt{LC}$,

$$\sqrt{LC} = \frac{1}{7914} \sqrt{0.0007075 \times 2.40377} = \frac{1}{7914 \times 10^6} \sqrt{7075 \times 240377} = \frac{41240}{7914 \times 10^6} = \frac{4124}{7914 \times 10^5} =$$

$$\frac{0.521}{10^5} = \text{roughly } \frac{0.52}{10^5} = \frac{52}{10^7} ! \quad (\text{Curious!}) \quad \text{see Colorado experiments.}$$

$$\text{Hence } \alpha = p \times \frac{52}{10^7} \quad \lambda = \frac{2\pi}{\alpha} = \frac{2\pi}{p \frac{52}{10^7}} = \frac{2\pi 10^7}{52p} = \frac{1,204,000}{p}$$

$$\text{or } \lambda = \frac{2\pi}{2\pi n \times \frac{52}{10^7}} = \frac{10^7}{52n} = \frac{192308}{n} \quad \text{this is } \frac{v}{n}.$$

Long Island apparatus

* M.F. in the manuscript – Ed.

Let the capacity of Earth be $707 \mu\text{F}^*$ and suppose frequency of 200 000 per sec. employed. The wave length will be not far from $\frac{186000}{200000} = 0.93$ miles. We may say for the present 1 mile. This will give 12000 complete waves over globe. Now the capacity of each half wave region should be on average $\frac{707 \times 9 \times 10^5}{24000} = \frac{636300}{24} = 26500 \text{ cm} = C$. Hence if the potential on free terminal of capacity $c = 4000$ be p , the potential of Earth will be $p \frac{c}{C}$. $\frac{4000}{26500} = \frac{4}{26}$ roughly $\frac{1}{7}$. This would be hardly possible.

The law of density will be truer. Assume equatorial region belt for half wave is 24000 square miles.

Sphere of 4000 cm capacity would have area of

$$\pi \times 8000^2 \text{ cm square} = \pi \times 80^2 \text{ square meters} = 10.78 \times \pi \times 6400 \text{ square feet.}$$

If density on terminal be σ then density on ground will be

$$\frac{10.78 \times \pi \times 6400}{\pi \times 8000 \times 53 \times 53 \times 10^4} \sigma = \frac{86.24}{2809 \times 10^5} \sigma.$$

The pressure will be regulated by density as assumed to have pressure proportional to density. Hence if pressure on terminal be only 200000 volts we should get on equator:

$$\frac{86.24 \times 200000}{28.09 \times 10^5} = \frac{172.48}{2809} = \frac{6}{100} \text{ Volt roughly}$$

Notes, experimental records, arrangements of oscillatory apparatus etc. imp.

Feb. to Sept. 1901

Feb. 2, 1901

From old notes

In many experiments with electrical oscillations of very high frequency curious spark discharges were observed which for long time could not be accounted for. Finally I found that they were due to exceptional rise by resonant action of the electromotive force. Further investigation led me to the discovery of fact that any conductor, say a straight wire telegraphic line cable etc. has a definite frequency at which the capacity just counteracts the inductance and when worked with currents of that frequency the conductor is capable of transmitting energy under conditions exceptionally favorable.

To get a rough idea suppose we use a concentric cable outside diam. R , inside diam. r .

The capacity $C = \frac{kl}{2 \log_e \frac{R}{r}}$. On the other hand the inductance $L = 2 \mu l \log_e \frac{R}{r}$. Now we should

have for series arrangement

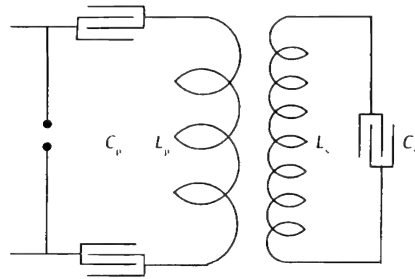
$$p = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\frac{kl}{2 \log_e \frac{R}{r}} \cdot 2 \mu l \log_e \frac{R}{r}}} = \frac{1}{l \sqrt{k \mu}} = \frac{3 \times 10^{10}}{l \sqrt{k \mu}}$$

Now $p = 6 \times 10^4$ say, $\mu = 1$. Taking $\sqrt{k} = 1.5$ we have $p = \frac{2 \times 10^{10}}{l}$ (in centimeter). $l = \frac{2 \times 10^{10}}{6 \times 10^4} = \frac{10^6}{3}$ = 330 meters. From this it would seem that such concentric cable worked with currents of above frequency would satisfy condition for every 330 meters of its length. But it should be remembered that in this case capacity and inductance can not be taken in series. When considered in multiple there ought to be a number of values. To follow up.

Feb. 24, 1901

Relations of primary and secondary

Consider a primary which is periodically closed and opened as in my coil with a resonating secondary in inductive but not too close relation as otherwise the free vibration would not properly assert itself. I shall first assume there is no ground connection and in general no cause to produce asymmetrical distribution. Diagram 1 below illustrates arrangement of the circuits which is familiar.



Calling combined capacity of the two condensers in primary circuit C_p , inductance of primary L_p , and C_s and L_s respectively the capacity and inductance of secondary circuit, and lastly M the mutual induction coefficient, we shall have during the time when the primary circuit is closed the inductance of the same reduced from L_p to a value $L_p \left(1 - \frac{M^2}{L_p L_s}\right)$. The period of the primary circuit when it is closed will thus be $T_p = \frac{2\pi}{10^3} \sqrt{C_p L_p \left(1 - \frac{M^2}{L_p L_s}\right)}$. Evidently for the best resonating condition the period of secondary when primary is opened should be the same. Now period of secondary will be $T_s = \frac{2\pi}{10^3} \sqrt{C_s L_s}$. Hence $C_p L_p \left(1 - \frac{M^2}{L_p L_s}\right) = C_s L_s$.

When the relation is satisfied we get one clear note in secondary. In practice C_s or L_s or C_p or L_p may be adjusted, also M in some instances when the secondary or primary are movable relative to each other. But in large apparatus this is obviously impracticable. A glance at the equation shows that if we seek values for L_p , L_s , or M we get more than one but there is only one value for either C_p or C_s . The above equation leads itself probably best for finding value of C_s which is

$$C_s = \frac{C_p L_p}{L_s} \left(1 - \frac{M^2}{L_s L_p} \right).$$

The above makes it clear that primary circuit when the secondary is removed should vibrate slower than the secondary alone. When they are linked together the primary vibrations must quicken up to the pitch of the secondary free vibrations. On the other hand there are two effects in the secondary produced by the primary which must exactly balance each other: There is a tendency created by the primary to slow down the free secondary vibrations because of the lower pitch and there is an other tendency of primary which is to quicken the free secondary vibrations by diminishing the self-induction coefficient L_s .

When the oscillations in the primary are arbitrary or forced as by a dynamo then the periods of secondary when primary closed and when opened must be equal. Putting it in symbols:

$$\frac{2\pi}{10^3} \sqrt{C_s L_s \left(1 - \frac{M^2}{L_s L_p} \right)} = \frac{2\pi}{10^3} \sqrt{C_s L_s}.$$

Hence $C_s L_s \left(1 - \frac{M^2}{L_s L_p} \right) = C_s L_s$ or $L_s L_p = M^2$. This means to say that the circuits are linked very closely as in ordinary transformers.

A few special cases are of interest. Suppose the ratio of conversion to be n , that is n times as many turns in the secondary as in primary. Assume the secondary turns bunched together then $L_s = n^2 L_p$ and in above equations C_s will then be

$$C_s = \frac{C_p L_p}{n^2 L_p} \left(1 - \frac{M^2}{L_p n^2 L_p} \right) = \frac{C_p}{n^2} \left[1 - \left(\frac{M}{L_p n} \right)^2 \right].$$

An other case is of interest. When $n = 1$ $L_p = L_s$. Then the equation becomes:

$$C_s = C_p \left[1 - \left(\frac{M}{L_p} \right)^2 \right],$$

from which either C_p or C_s may be found which ever it may be more suitable to adjust.

Note: From above relations the material coefficient may also be determined by resonance method.

It is easy by adjustment of one or the other of the quantities to produce two notes of distinct pitch such as will interfere least with one another. This is important in connection with my improvements in signaling and also in other respects.

$$\text{We have found that } T_s = \frac{2\pi}{10^3} \sqrt{C_s L_s} \text{ and } T_p = \frac{2\pi}{10^3} \sqrt{C_p L_p \left(1 - \frac{M^2}{L_s L_p} \right)}.$$

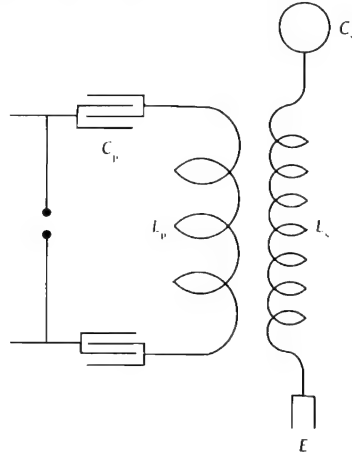
Now T_s and T_p should as I have found in practice be selected as primary (relative) numbers so as to get the greatest number of beats per unit of time. In this case the vibrations interfere least, because the periods when they cooperate and those when they work against each other follow in most rapid succession. At any rate in the receivers greatest safety against disturbance is seemed when the periods of the tuned circuits are so related. We may put

$$\frac{T_s}{T_p} = \frac{M}{n}.$$

Hence

$$\frac{C_s L_s}{C_p L_p \left(1 - \frac{M^2}{L_s L_p}\right)} = \frac{M^2}{n_2} = K \text{ and } C_s L_s = K C_p L_p \left(1 - \frac{M^2}{L_s L_p}\right).$$

From this later equation one or the other of the constants, which ever is found to be more convenient, may be calculated.



The above found relations are modified in case of earth connection or general asymmetry. In case of earth connection we have approximately (only secondary being connected to ground), since the secondary now will vibrate just half the period, if the quantities designated by letters have same values as before:

$$4 C_p L_p \left(1 - \frac{M^2}{L_s L_p}\right) = C_s L_s \text{ for one clear note}$$

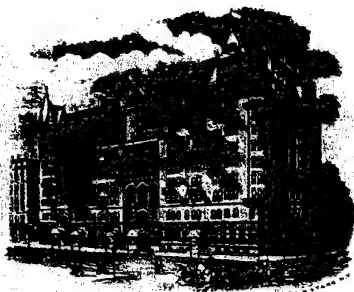
and

$$4 K C_p L_p \left(1 - \frac{M^2}{L_s L_p}\right) = C_s L_s \text{ for two notes as above explained.}$$

Evidently to satisfy resonating conditions the capacity and induction in primary will each have to be doubled. Theoretically this is so, but in practice it is found that they need not be quite double. The reason is that capacity effect of coil L_s is smaller relatively then when coil used without earth.

Various reflections to follow

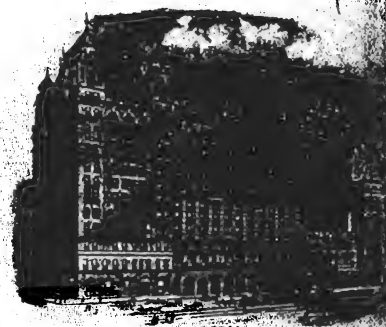
NEW YORK CABLE ADDRESS, "BOLDT, NEW YORK"
PHILADELPHIA CABLE ADDRESS, "BOLDT, PHILADELPHIA"



THE WALDORF
THE WALDORF-ASTORIA, NEW YORK
HOTEL BELLEVUE, PHILADELPHIA
THE STRATFORD, PHILADELPHIA
BULLITT BUILDING RESTAURANT, PHILADELPHIA
GEO. C. BOLDT, PROP.

The Waldorf-Astoria,

Fifth Avenue, 33rd and 34th Streets
and Astor Court.



THE ASTORIA

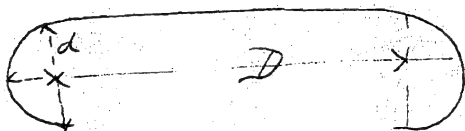


New York March 1 1901

from old note:

Considerations relative transmission to great distance through Earth by my system.

assume I use a terminal elevated at 300 feet. This height might be obtained with three lengths of gal. pipe lined by steel pipes. For the first plant I would be better to work to work as other mechanical engineering. Later some of the engineering with metal or masonry supports should be devised may be used. Possibly a single chimney in center may be used if terminal small. Three chimneys at any rate will be sufficient. Let the insulated terminal be in the form of a roof flat, with broadened sides as a sketch.



$$\text{length: } \frac{\pi}{4} D^2 + \frac{\pi}{2} d \cdot \pi(D+d) = S$$

Suppose $D = 700$ meter or say 200 ft

$d = 10$ meter or say 30 feet

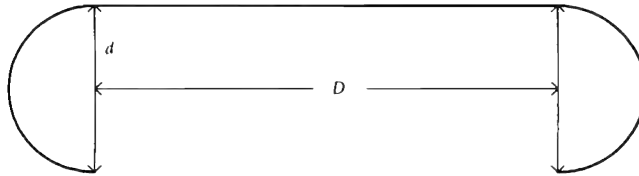
Then $S = 0.7854 \times 490000 + 10.30 \cdot 330 = \text{say } 170000 \text{ square feet}$

The capacity of roof or terminal will be not far from 4000 c. m. and at a height of 300 feet this ought to be about 10000 c. m. If the frequency

1)

Considerations relative transmission to great distance through Earth by my system

Assume I use a terminal elevated at 300 feet. This height* might have been attained with three lengths of Cal. pine joined by steel pipes. For the first plant it would be better to resort to wood as other material expensive. Later some of the arrangements with metal or masonry supports which I have devised may be used. Possibly a single chimney in center may be used if terminal small. Three chimneys at any rate will be sufficient. Let the insulated terminal be in the form of a roof flat, with toroidal rim as in sketch.



Surface of the roof will be roughly: $\frac{\pi}{4}D^2 + \frac{\pi}{2}d\pi(D+d) = S$.

Suppose $D = 100$ meter or say 300 feet, $d = 10$ meter or say 30 feet. Then $S = 0.7854 \times 90000 + 10 \cdot 30 \cdot 330 =$ say 170000 square feet. The capacity of roof or terminal will be not far from 4000 cm and at a height of 300 feet this ought to be about 10000 cm.

If the frequency be 50000 per sec. we have:

$$\frac{1}{50000} = \frac{2\pi}{10^3} \sqrt{\frac{10^4}{9 \times 10^5}} L \quad \text{and} \quad L = \frac{9}{10^4} \text{ Henry}$$

This might do but it will probably be preferable to match the length of wire 3 quarter of wave or $(n + 1)$ quarters where n even number. This will give more prolonged vibration on account of greater inductance associated with system.

It is interesting to see what would be attained with the ordinary frequency of alternator say 125 cycles. In this case $\frac{1}{125} = \frac{2\pi}{10^3} \sqrt{\frac{10^4}{9 \times 10^5}} L_1$ and $L_1 = 144$ Henry about. This inductance could scarcely be obtained without iron. For trial suppose drum 6 feet diam. $A = 24000$ cm square. Wound with wire N^o 20 and string equal thickness. Spool of 100 feet length would have about 12000 turns (120 turns per foot).

This would give the inductance of spool $L_2 = \frac{4\pi \times 24000 \times 144 \times 10^6}{100 \times 12 \times 2.5} = 14$ Henry approx. Evidently too little

unless we use larger diameter. If the spool were about 20 feet it would be possible. The section or area of spool would then be more than 10 times and induction more than 10 times larger which would bring it to about the value required. The string between the turns might stand 5000 Volts. Hence it would be roughly considered possible to get a pressure of $5000 \times 12000 = 60 \times 10^6$ Volts. This is evidently exaggerated estimate probably only 1000 Volts between each turn would be practicable and all that could be reached would be scarcely more than $1000 \times 12000 = 12$ million Volts. Of course this could imply an enormous magnifying factor which could not be attained. For the length of wire N^o 20 would be about $60 \times 12000 = 720000$ feet and resistance about 7200 Ohms. p being $= 2\pi \cdot 125 = 800$ approx. and $L_2 = 140$ Henry the magnifying factor would be $\frac{140 \times 800}{7200} = 140:9 = 16$ approx. The supply transformer might give 50000 Volts and this would only rise to $16 \times 500000 = 8,000,000$ Volts.

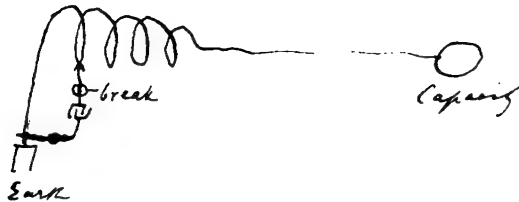
Suppose we have to charge roof to one million Volts. What would be effect at equator?

* Tesla's erroneous spelling of some english words in the manuscript (e.g. *accross*, *hight*, *chocking*, *inclosure*, and writing some compounds as one word (e.g. *sparkgap*, *watermain*, *groundwire*) has been corrected in this edition.

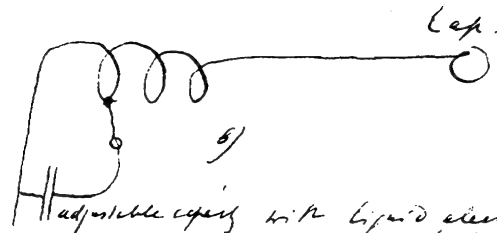
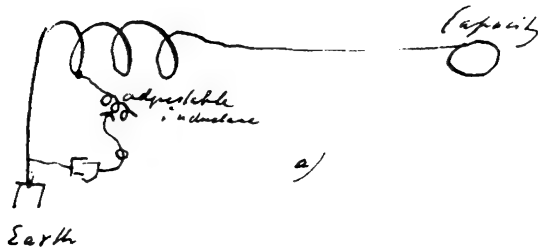
March 24, 1901.



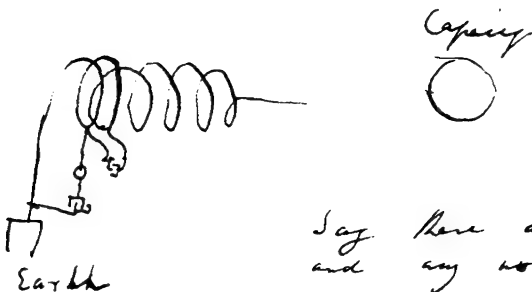
Some of the preferred arrangements for getting the secondary circuit in tune with primary when latter is closed and also when opened, furthermore for getting any desired relation between the rates of vibration when closed and when opened.



In this case a point is found along the condenser when Synchronization exists or else when the desired relation is attained.



In a) and b) by adjustment with fixed length of primary & secondary. Adjustable capacity with liquid electrolyte Condenser preferably.



This is very good for prolonging vibrations and exciting better the reel system (secondary).

Say there are two primary coils in the primary and any number of secondary coils. All in series.

The first primary has gets the condenser discharges - that is the turn nearest to ground (connected to earth). The second primary has in very close inductive relation to first and shunted with a condenser and tuned to primary. When first has interrupted second has a broken long.

When using secondary to close relation and series in a primary the latter may be, opposing wound or in same direction. Specific results.

$$\text{Density } D = \frac{p}{S} = \frac{10^6}{17000 \times 144 \times 6.5} \text{ on roof}$$

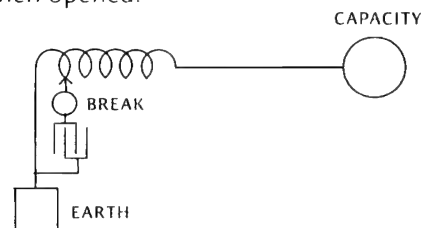
Surface of equatorial belt 1 mile wide (two miles or one half wave reduced to uniform electric field)

$$\text{Surface of equatorial belt } S_1 = 8000 \times \pi \times 5300 \times 5300 \times 144 \times 6.5$$

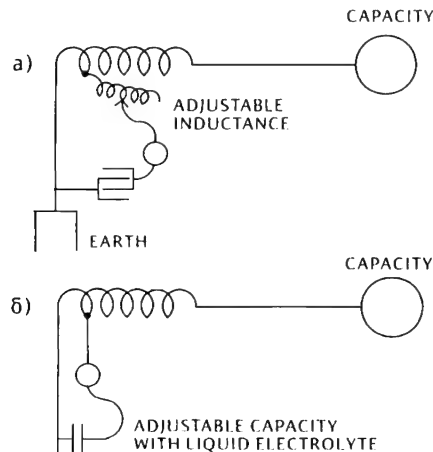
Hence density $d = \frac{10^6}{17000 \times 144 \times 6.5 \times 8000 \times \pi \times 53 \times 53 \times 10^4 \times 144 \times 6.5}$. If same kind of roof or terminal be used on equator the pressure initial would be $p = \frac{1}{8 \times 65 \times 144 \times 53^2 \times \pi}$ roughly $\frac{1}{6 \times 10^8}$ Volt. Assume magnifying factor 10000 the volts would be $\frac{1}{6 \times 10^4}$. Apparent energy: $\frac{1}{2} \cdot \frac{1}{36 \times 10^8} \cdot 10^5 \cdot 10^4 = \frac{5}{36}$ Watts. Plenty.

March 24, 1901

Some of the preferred arrangements for getting the secondary circuit in tune with primary when latter is closed and also when opened. Furthermore for getting any derived relation between the rates of vibration when closed and when opened.



In this case a point is formed along the conductor when synchronism exists or else when the desired relation is attained adjustable capacity with liquid electrolyte condenser preferably.

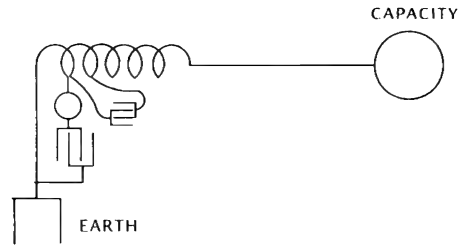


In a) and b) by adjustment with fixed length of primary and secondary

This is very good for prolonging vibrations and exciting better the real system (secondary)

Say there are two turns which are the primary and any number of secondary turns. All in series. The first primary turn gets the condenser discharges – that is the turn nearest to ground (connected to Earth). The second primary turn in very close inductive relation to first and shunted with a condenser and tuned to primary. When first turn interrupted second turn vibrates long

When using secondary in close relation and series with primary the latter may be oppositely wound or in same direction. Specific results.



April 1, 1901

From old notes

Transmission without wires to great distances considered

Suppose my insulated terminal be a metallic roof as proposed before. It is easy to get 6000 cm. Let the capacity be charged to one million Volts we have

$Q = \frac{6000}{9 \times 10^{11}} \cdot 10^6 = \frac{2}{300}$ Coulomb. Estimated surface in centimeter of roof approximately 26×10^7 cm square.

I shall assume that the waves used be four miles long. Then belt on equator of Earth (taken with reference to transmission station as a pole) will be: $2 \times \pi \times 8000$ square miles. Taking for the present the electric density of ground charged by the wave uniform we may take about $\frac{2}{3}$ of above value in estimate to follow. This gives about 32000 square miles of uniformly charged surface. Or $5300 \times 5300 \times 32000 \times 144 \times 6.5$ centim. square approximately. The electric densities on roof and equatorial belt will be as $\frac{26 \times 10^7}{53 \times 53 \times 32 \times 10^4 \times 144 \times 6.5} = \frac{1}{220000 \times 144} = \frac{1}{3 \times 10^7}$, since densities must be inversely as the areas charged. Now density on roof or terminal when charged to one million Volts will be $\frac{2}{3 \times 100 \times 26 \times 10^7} = \frac{1}{39 \times 10^9}$ that is approx. $\frac{1}{4 \times 10^{10}}$.

Hence density on equatorial belt will be $\frac{1}{4 \times 10^{10} \times 3 \times 10^7} = \frac{1}{12 \times 10^{17}}$.

Suppose now at the receiving station a similar roof or terminal it will get a minimum quantity of electricity $26 \times 10^7 \times \frac{1}{12 \times 10^{17}} = \frac{26}{12 \times 10^{10}}$ or approx. $\frac{2}{10^{10}}$ Coulombs. From this we shall get the pressure $p = \frac{q}{C} = \frac{10^{10}}{\frac{6000}{9 \times 10^{11}}} = \frac{3}{100}$ Volt.

Now, if we would not magnify at all we would get energy:

$$E = \frac{1}{2} \times 100000 \times \left(\frac{3}{100} \right)^2 \frac{6000}{9 \times 10^{11}} = \frac{3}{10^7} \text{ Watts under the conditions assumed.}$$

But if a magnifying factor of only 10000 which is quite practicable be used taken with reference to one second then if one signal needed $\frac{1}{100}$ second we should still magnify 100 times and would get apparent energy of $\frac{3}{10^5}$ Watts. Taking transmission across the diameter of Earth to a distance of 8000

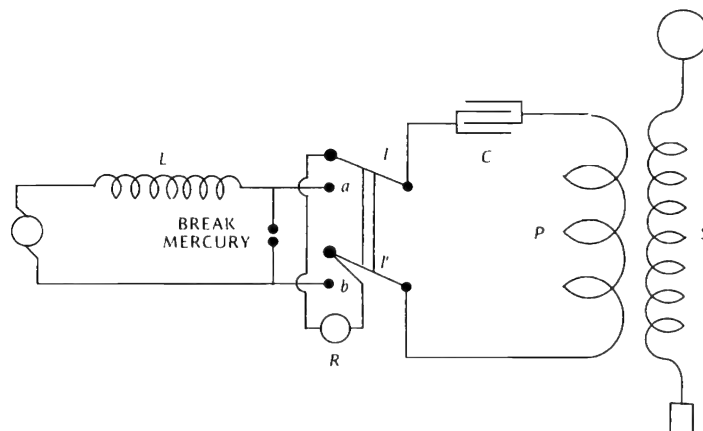
miles straight line the density would be at the pole about $\frac{32000}{24} = \frac{4000}{3}$ times greater. Since excitation is proportionate to density (important fact!) we would get apparent energy $\left(\frac{4000}{3}\right)^2$ times more energy because e.m.f. would be $\frac{4000}{3}$ times greater. Or apparent energy gathered in a station at the pole would be $\frac{16 \times 10^6}{9} \times \frac{3}{10^5} = \frac{480}{9} = 53 \text{ Watts!! approx. Great!}$

P.S. It would be easy to get by surfaces of small curvature larger capacity.

We could light a lamp at the pole no doubt.

From old notes

Following arrangement with ordinary form of oscillator and as used on supply circuits in the laboratory has been found convenient for use in signaling. The idea is to use the apparatus alternately as transmitter and receiver by simply changing its connection with a switch which may be automatic in returning to the position of receiving.



L induction for primary raising pressure of supply circuit as used. C and P condenser and primary. S secondary which may be either directly used in the transmission to a distance or for exciting of other circuit, R is the receiving circuit with the sensitive receiver in any suitable way arranged. $I I'$ are the arms of switch. In position indicated the apparatus is ready to receive. The secondary S being in tune with vibrations from distanced transmitter is excited and induces currents in primary circuit. $P C R$ likewise tuned.

When switch placed in position ab then the receiving circuit R is disconnected and the apparatus transmits. The arrangement is very simple and suitable particularly for transmissions to small distances. It can be arranged in a small compass.

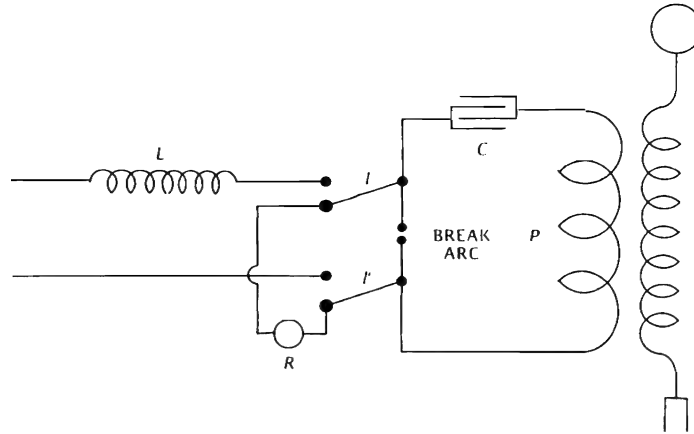
— . —

Following modified disposition is adopted as suitable when break is an arc and hot mercury an other contact making device.

The letters signify corresponding parts as on sheet preceding. This same arrangement I find can be used for determining resistance of arc in following manner.

First, coil S adjusted to be in resonance with primary excited system with the arc playing, then the coil is excited from an other source and resistance R is varied until again resonance attained in primary system. The switch $I I'$ may be operated by hand or be made automatic as in ordinary key. A controlling magnet also may be used for shifting, the levers $I I'$ and the magnet may be controlled by a key as usual.

The above arrangement is not practicable with the mercury break unless the same be stopped when receiving. This of course can be done. At any rate useful data may be gained in experiments to ascertain resist. actual of break e t c.



To follow up.

April 15, 1901

Considerations relative to terminal in transmitter for transoceanic plant in process of construction

Compare insulated roof disk form rounded on ends in form of torus with condenser comprising two plates. The roof should be at some distance from Earth's surface that the capacity relative to Earth is small under which condition most of charge will be "free".

We have for condenser of two disks $C = \frac{\pi r^2}{4\pi b} = \frac{r^2}{4b}$ where b = distance from Earth's surface, r = radius of disk.

At present it will be sufficient to assume roof as straight disk.

For one disk (roof) alone, $C_1 = \frac{2r}{\pi}$, k assumed = 1, C = capacity of roof on Earth's conducting surface, C_1 = capacity far removed from Earth's conducting surface.

$$\text{From this} \quad \frac{C}{C_1} = \frac{\pi r^2}{2r \times 4b} = \frac{\pi r}{8b}$$

$$\text{For} \quad b = r \quad \frac{C}{C_1} = \frac{\pi}{8}$$

$$b = 2r \quad \frac{C}{C_1} = \frac{\pi}{16}$$

$$b = \pi r \quad \frac{C}{C_1} = \frac{1}{8}$$

This last means to say that if the conducting disk or roof be say of radius $r = 200$ feet the elevation should be 300 feet to have say $\frac{1}{8}$ of effectiveness or effective capacity. But now there is an increase of capacity as I find of about $\frac{1}{2}\%$ per foot of elevation. This means 150% for 300 feet. Consequently the actual ratio $\frac{C}{C_1}$ will be instead of $\frac{1}{8}$ $\frac{1}{8 \times 2.5} = \frac{1}{20}$. From this it would seem that 200 feet would be all that is needed to work with fair economy.

Inductance coils to be placed in series with closed iron circuit Westinghouse transformer for the purpose of raising pressure, preventing short-circuiting by break and increasing economy. Two spools 19" outside diam. 5" inside are made. They are 2½" wide but space for wire available will be only 2". There will be about necessary wire as follows:

Average diam. 12". The inductance of one turn will be approximately $\frac{1}{64} \times 8000 = 125$ cm. (8000 cm being inductance of loop 8 feet diam.)

As found before for resonating condition we shall want $\frac{10}{6}$ Henry in each coil.

$$\text{Now } \frac{10}{6} \times 10^9 : 125 = N^2 : 1 \quad N^2 = \frac{10^{10}}{750} = \frac{10^9}{75}$$

$$N = 10^4 \sqrt{\frac{10}{75}} = 3700 \text{ turns approx.}$$

With № 16 wire we get 32 turns per 2". This would require $3700:32 = 120$ layers (about). This would need 8" space wound. We have only 7". Wire № 16 will want 3" width. This per layer gives 48 turns and 80 layers would be sufficient. The space needed $80 : 16 = 5"$ fully enough. In as much as №. 16 wire has an unnecessarily large section we may take №. 18 double covered, fiber between layers ¼" (final).

April 28, 1901

Considerations relative to elevated terminal

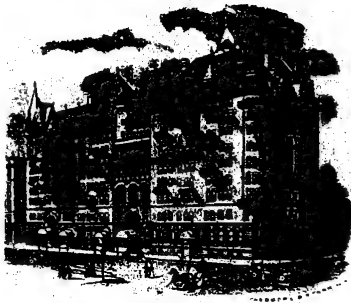
It is for practical reasons desirable to get along with the smallest height and also with the least surface because these two influence largely the cost.

As to elevation it ought to be such that most of the charge is free. In other words – the capacity with reference to Earth should be much smaller than that of the surface of terminal itself considered as far remote from other conducting bodies.

Regarding the form I have found that for many reasons it would be best to employ a sphere with the lower part less than one half open, but it may be difficult to construct such a terminal. A plane roof or surface with rounded circumference (of large radius of curvature) would seem easiest to construct and also appears to be the cheapest. A sphere, it is true, might be made smaller than any other terminal because it would allow the charging to the highest pressure. Next to sphere a cylinder with half spherical ends seems best. To get an idea suppose the terminal to be in the shape of a disk or plane with rounded edge (in the shape of a tore if the radius be r the capacity would be $\frac{2r}{\pi}$. Taking value assumed in above estimates $\frac{2r}{\pi} = 10000$. Hence $r = 15700$ cm or 157 meter.

Now the disk would have to be at a height such that its capacity with reference to an other surface on the ground would be much smaller. Suppose an other disk of the same dimensions were on the ground then the capacity of the condenser so formed would be $\frac{S}{4\pi b} = \frac{\pi r^2}{4\pi b} = \frac{r^2}{4b}$. The ratio of both the capacities is $\frac{2r}{\pi} : \frac{r^2}{4b} = \frac{4b \times 2r}{r^2 \pi} = \frac{8b}{r\pi}$. Here b is the height. Suppose we take this ratio = 10, we have for b value $\frac{8b}{r\pi} = 10$, $b = \frac{10r\pi}{8} = \frac{1570\pi}{8} = 616$ approx. This shows that under the above conditions the height would have to be very large. It is clear that the larger the plane conducting surface the greater will have to be the height to satisfy above relation. For $b = \frac{r\pi k}{8}$, where k is the number expressing ratio. As it is

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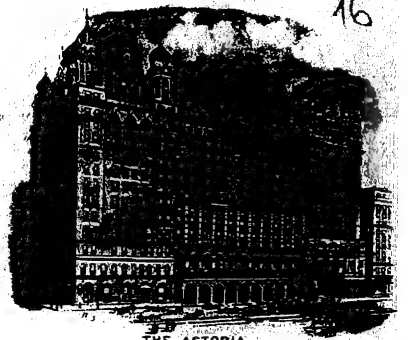


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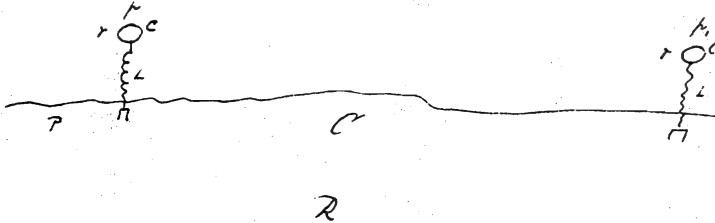


THE ASTORIA



New York April 28 1901

Signalling through the earth with open synchronous circuits
Theoretical considerations; low frequency impulses.



C capacity of isolated terminal assumed to be a sphere at some distance from the Earth's surface the work of its charge is "free".
 C capacity of earth
 R radius of sphere.
 r " of sphere.
 L oscillating coil.

A certain quantity of electricity being conveyed to the sphere a corresponding quantity will be abstracted from the globe and the potential on the latter will alternately rise and fall according to the sign of electricity conveyed to the sphere.

Let the quantity of each alternation be q and if the quantity of electricity in the earth then there will be a variation of $(Q+q)-(Q-q) = 2q$ coulombs during one complete cycle in the earth.

Since $q = pC$ (p being the potential of sphere charged w.r. to earth)
 $Q = PC$ " " " "

the variation of potential will be $(PC+pC)-(PC-pC) = 2pC$ per cycle

1).

seen b is proportionate to r . If therefore instead of having 157 meter radius the conducting surface is only 15.7 meter radius the height required would be only 61.6 meter which is reasonable.

This shows the importance of having the terminal small to avoid great expense in the construction of same. Evidently the same electrical movement as before could be attained with a small terminal charged to a corresponding higher pressure.

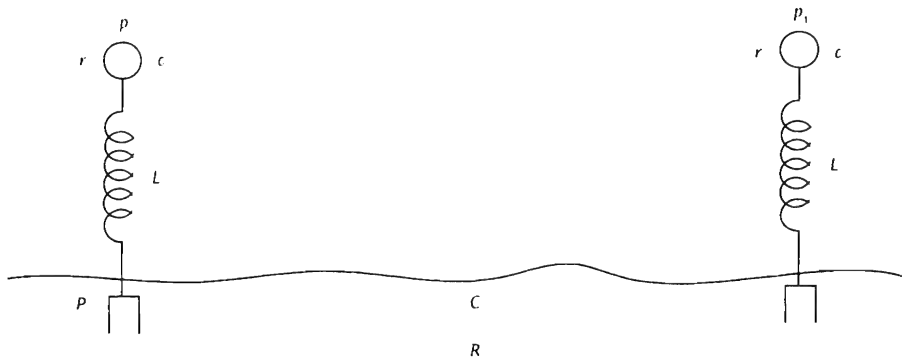
We have assumed before 10000 cm capacity charged to 288000 which would give at any point of the globe a pressure of $\frac{7}{10^5}$ Volt for exciting the receiving circuit. But since Q the quantity of electricity stored $= p' C' = p'' C'' = p''' C'''$ etc. the capacity may be made smaller in the same ratio as the pressure is increased. Now how far can the pressure be carried is important to ascertain.

Suppose first that the frequency of the dynamo say 60 cycles be used and by a step up transformer of the type I employ in wireless transmission the e.m.f. raised. For closed iron core transformers (unless supplied from insulated, independent sources) the e.m.f. of 288000 Volts is about as high as could be carried even with oil insulation. But with the above transformer properly constructed I think a ten times greater e.m.f. might be attained. This would mean that to produce same el. movement as previously considered with capacity 10000 cm we would want only a capacity of 1000 cm or the disk would have to be of 15.7 meter radius. But to charge a capacity of 1000 cm to a pressure 10 times greater would require 10 times as much energy as before ascertained since $\frac{1}{2} p^2 C : \frac{1}{2} p_1^2 C_1 = \frac{p^2 C}{p_1^2 C_1} \cdot p = 10 p_1 C$
 $= \frac{1}{10} C_1, \frac{p^2 C}{p_1^2 C_1} = \frac{100 p_1^2 C}{p_1^2 C_1}$ or 10.

To be continued

Signalling through the Earth with open syntonized circuits

Theoretical considerations in low frequency impulses



c capacity of insulated terminal assumed to be a sphere at such distance from the Earth's surface that most of its charge is "free".

C capacity of Earth,

R radius of "

r " of sphere

L oscillating coil

A certain quantity of electricity being conveyed to the sphere a corresponding quantity will be abstracted from the globe and the potential on the latter will alternately rise and fall according to the sign of electricity conveyed to the sphere.

Let the quantity at each alternation be q and Q the quantity of electricity in the Earth then there will be a variation of $(Q + q) - (Q - q) = 2q$ Coulombs during one complete cycle in the Earth.

Since $q = pc$ (p being the potential of sphere charged max.)

$$Q = PC \quad (P \quad " \quad " \quad \text{Earth})$$

the variation of potential will be $(PC + pc) - (PC - pc) = 2pc$ per cycle.

Now the electric density (max.) on sphere will be $\frac{q}{s}$ and on Earth $\frac{Q}{S}$, s and S being the surfaces of the sphere and of Earth respectively. The total variation during one whole cycle of density on Earth surface will be: $\frac{Q+q}{S} - \frac{Q-q}{S} = \frac{2q}{S}$. Of course this holds so far only for cycles sufficiently slow to allow the charge to distribute itself completely each time which means comparatively very slow frequency. The charge passes chiefly on the surface as far as I have found and therefore, taken the diam. of Earth 12,700,000 meters, the half wavelength should under above assumption not exceed 12,700,000 π meters. Taking speed of electricity 320,000,000 meters per sec. we would have about only $32 \times 10^7 : 254 \times \pi \times 10^5 = 4$ cycles per second approx. I shall first consider the case as assumed although it has many practical disadvantages. Higher frequencies will be subsequently treated.

Since the variation of density during cycle is $\frac{2q}{S}$ it will be important to ascertain how large q can be made in my machines without great practical inconveniences.

Suppose I use a two pole machine rotating four times per second or 240 times per minute directly driven an engine. Let the horsepower be 500 H.P. This means 736×500 Watts per sec. approx. Since there will be 4 cycles per sec. we shall have per each alternation $\frac{736 \times 500}{8}$ Watts. This energy should be stored in condenser c each time.

Hence: $\frac{1}{2}p^2c = \frac{736 \times 500}{8}$ from which we may get an idea of the two quantities p and c .

There is no great difficulty in using for capacity an insulated surface or roof such that $c = 10000$ cm. In such case $\frac{1}{2}p^2 \cdot \frac{10000}{9 \times 10^{11}} = \frac{736 \times 500}{8}$ and

$$p^2 = \frac{2 \times 9 \times 10^7 \times 736 \times 500}{8} = 18 \times 10^7 \times 500 \times 92 = 828 \times 10^{10}$$

$$\text{and } p = 10^5 \sqrt{828} = 10^5 \cdot 2.88 = 288000 \text{ Volts.}$$

From this approximate estimate it would seem that q can be easily made:

$$q = 288000 \times \frac{10^4}{9 \times 10^{11}} = \frac{288}{9 \times 10^4} = \frac{32}{10^4} = q$$

Taking this figure we would get total variation of el. density on Earth's surface during one cycle:

$$\frac{2 \times 32}{S \times 10^4} \text{ or the variation for one half would be } \frac{32}{S \times 10^4}.$$

If we assume at a receiving station (irrespective of distance for the present) an other conducting surface of same extent the results will be as follows:

The roof will be naturally flat or a plane with round circumference but for sake of simplicity we may assume now that it is a sphere of radius 100 meters = r .

Since $\frac{q_1}{s} = \text{density} = \frac{32}{S \times 10^4}$ we shall have:

$$q_1 = \frac{s}{S} \cdot \frac{32}{10^4} \text{ as the quantity of electricity collected at each half cycle at the receiving station.}$$

$$\text{From this we find } q_1 = p_1 c = \frac{s}{S} \cdot \frac{32}{10^4}$$

$$p_1 = \frac{s}{Sc} \cdot \frac{32}{10^4}, p_1 \text{ being the potential to which receiving terminal will be charged each time.}$$

Now

$$\left. \begin{aligned} s &= 4 \pi r^2 \\ S &= 4 \pi R^2 \end{aligned} \right\} \text{ therefore } \frac{s}{S} = \left(\frac{r}{R} \right)^2$$

Substituting the quantities found and assumed:

We have

$$p_1 = \left(\frac{100}{\frac{12700000}{2}} \right)^2 \cdot \frac{32}{10^4 \cdot \frac{10000}{9 \times 10^{11}}} = \left(\frac{1}{63500} \right)^2 \cdot 288000 = \frac{1}{(635)^2} \cdot 28.8 = 0.00007 = \frac{7}{10^5} \text{ Volt approx.}$$

The energy stored will be

$$\frac{1}{2} p_1^2 c = \frac{1}{2} \left(\frac{7}{10^5} \right)^2 \cdot \frac{10^4}{9 \times 10^{11}} = \frac{49}{18 \times 10^{17}} \text{ Watts.}$$

This energy would be available at each charge for operating a device at no matter what distance.

The quantity of electricity available will be as before found:

$$\begin{aligned} q_1 &= \frac{s}{S} \cdot \frac{32}{10^4} = \left(\frac{200}{12700000} \right)^2 \cdot \frac{32}{10^4} = \frac{1}{(63500)^2} \cdot \frac{32}{10^4} \\ &= \frac{1}{(635)^2} \cdot \frac{32}{10^8} = \frac{1}{126 \times 10^{10}} \text{ Coulomb.} \end{aligned}$$

Even one discharge would be sufficient to send a perceptible signal under the conditions assumed. (The special calculation to be added).

We may, however, without using any greater quantity of actual energy make available for the operation of a device a vastly greater amount energy. If one signal per second were required the energy available would be $8 \times \frac{49}{18 \times 10^{17}} \text{ Watts} = \frac{392}{18 \times 10^{17}} = \frac{21.7}{10^{17}}$ roughly $\frac{2}{10^{16}} \text{ Watt.}$

Per minute one signal we could make available by the process of storing as described in my patents:

$$\frac{120}{10^{16}} = \frac{12}{10^{15}} \text{ Watt.}$$

Evidently a signal can even under the above enormously unfavorable conditions be transmitted by such apparatus as I contemplate using.

The conditions could be greatly improved by raising the pressure say to 10 times the value in which case the effect at distance would be 100 times as great. The amount of power required would still not be prohibitory. In fact as the power is only intermittently used it might not be necessary to use a greater amount of actual power. The preceding considerations have been made without regard to the great advantages which can be secured in my tuned system.

In this case to begin with the generator we can raise the pressure at the terminal to a value greater in the proportion of $\frac{p'L}{R}$ than the one before found. In the case assumed p' would be $= 2\pi n$ roughly $= 24$. The ratio $\frac{L}{R}$ is merely a question of copper. If this ratio were but $= 1$ we still would have the e.m.f. at the transmitter end 24 times the value above assumed.

Suppose further that the receiver is equally proportioned. Then the electrical movement in the receiving circuit would be magnified $(24)^2$ times. We would thus have $\frac{(24)^2}{126 \times 10^{10}}$ Coulombs per second available for operating an instrument which should be one dependent on the quality of energy that is not requiring a great amount of actual energy. This gives $\frac{46}{10^{11}}$ Coulomb. Thus the current obtained in the receiving circuit would be $i = ec\omega = \frac{46}{10^{11}}$ Amperes. There are many instruments responding to a flow of $\frac{1}{10^{11}}$ Amperes. That signals can be transmitted to any distance by my system is therefore perfectly sure.

Higher frequencies considered

Experiments in Colorado have demonstrated that waves with crests and hollows can be made to pass over the globe when the intensities of the impulses are enormous. With such impulses the transmission to any distance is quite easy.

First I shall consider the frequency obtained with dynamo ordered for transatlantic plant, 60 cycles per second. The wavelength λ is $= \frac{320000000}{60} = 5333000$ meters or 5333 kilometers.

There will then be according to my experience belts of alternating high and low density $\frac{5333000}{2}$ meters wide. At the equator the density will be smallest – that is at the equator relative to which the transmitting point or station is a pole. Taking the more unfavorable case – the transmission to a point in the equatorial region we shall have: $s_1 = \pi d \times \frac{\lambda}{2}$ approximately. I assume for sake of simplicity that the curvature is ignored and the zone or belt considered cylindrical. It would be close enough for present purposes.

Evidently the density will now come out in the same ratio greater as the surface s_1 is smaller than the total Earth's surface. The latter is $S = \pi D^2$, hence density in present case will be

$$d_1 = \frac{\pi D^2}{\pi D \frac{\lambda}{2}} \cdot d = \frac{2D\pi d}{\lambda}, \quad d \text{ being the density before ascertained.}$$

$$\frac{2D}{\lambda} = \frac{12,700,000 \times 2 \times 60 \times \pi}{320,000,000} = 4.76 \times \pi = 15d \text{ nearly.}^*$$

* Tesla's lapse, i.e.
 $2D/\lambda = 4.76$. - Ed.

As the density is 15 times that found before the pressure at the terminal of receiving station will be in same ratio greater and that means that the energy stored per one charge will be 15^2 times or 225 times greater. This would be the case if the impulses were of the same intensity as before assumed but we must consider that the energy if the dynamo is the same as before, consequently the energy of each impulse will be reduced in the ratio of their number. Taking 60 per sec. as compared with 4 per second the energy of each of the impulses of the higher frequency will be $\frac{1}{15}$. Therefore the energy at each change will be only 15 times greater at each half cycle. Nevertheless the advantage is very great as it is, for we can now accumulate in the same time interval a much greater electrical movement than it was possible with the frequency first assumed. Not considering the advantages of resonance we would get $\frac{60}{4} \cdot 15$ times or 15^2 times the energy before received per sec. That is, we would have for the operation of the receiving device an electrical movement 225 times greater at our disposal or in figures:

$$\frac{8 \times 225}{126 \times 10^{10}} = \frac{1800}{126 \times 10^{10}} = \frac{18}{126 \times 10^8} \text{ Coulombs of electricity per sec.}$$

The current would be $\frac{18}{126 \times 10^8}$ Amp evidently ample.

Suppose however we use carefully adjusted syntonized circuits, then the e.m.f. at transmitter could be raised in ratio $\frac{377}{1}$ approx. assuming again $\frac{L}{R} = 1$, and on receiver we would get an electrical movement

$$\frac{(377)^2}{126 \times 10^{10}} = \frac{142}{126 \times 10^7} \text{ approx. and a current of nearly } \frac{142}{126 \times 10^7} \text{ Amperes.}$$

This is many times larger than required.

Still higher frequencies will give greater amperage and in proportion to the square of the frequency. Hence if I use 100 000 per sec instead of 4 as first contemplated there would be per second available an electrical movement of rate equal to $\left(\frac{25000}{4}\right)^2 \cdot \frac{1}{126 \times 10^{10}} = \frac{625 \times 10^6}{16} \cdot \frac{1}{126 \times 10^{10}} = \frac{625}{16 \times 126 \times 10^{10}} = \frac{100}{31 \times 10^4} = \frac{1}{3100}$ Coul. and we would get current $\frac{1}{3100}$ Amperes. This would be amply sufficient for operating a rough instrument. At the poles or any other point not in the equatorial belt the figures would come out still more favorable to the transmission which as has been before recorded would be easiest effected to the opposite pole that is to the point diametrically opposite to the transmitting station, at least this is theoretically reasonable to assume.

For the last frequency we should now take correction. First of all I shall have instead of 500 H.P. only 150 H.P. available. Then there may be some limitations to the capacity. This latter limitation I do not feel as if the surface is smaller the potential may be correspondingly raised. It is fair to take correction only for power; this means that instead of above value the current will be only $\frac{150}{500} \cdot \frac{1}{3100}$ Amperes $= \frac{1}{10000}$ Amperes approx. But it still to be borne in mind, that this would mean only one signal per second. If we take 10 signals per sec then the amperes obtained would be only $\frac{1}{100}$ that is $\frac{1}{1,000,000}$ Amperes but even in this case it is ample for operating an instrument of the ordinary kind.

Consider further that I have assumed above $\frac{L}{R} = 1$. This is very insignificant. Usually $\frac{L}{R}$ will be large – at least = 10. All this will make the actual result ever so much better then would be inferred from this rough estimate. Evidently $\frac{L}{R}$ should be made as large as it can be made without great expense which would be prohibitory. Cooling the conductors may pay very well. Investigate further.

— . —

Following principle seems to me very good in connection with signaling.

At receiver station the energy is utilized to alter the pressure on a microphone contact and thus produces an action on any kind of receiver.

Scheme:

A receiving circuit

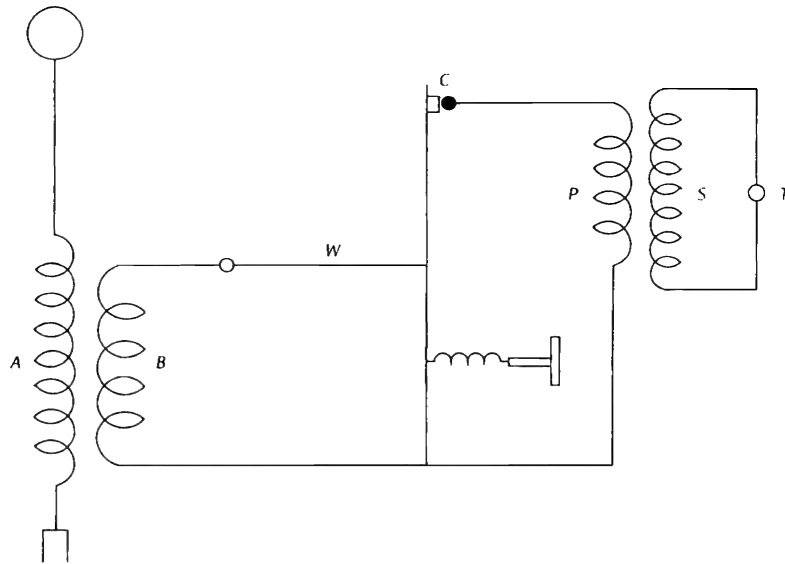
B secondary as in my system

w wire of small mass

c microphonic contact the pressure of which is adjusted by adjustable spring

p and s are the primary and secondary respectively of an induction coil

T is a telephone or other device



When the signal is sent, wire *w* is heated, elongates, and the pressure at *C* is increased. The stronger current passing through *p* induced current in *S* actuates *T*. The principle is capable of many modifications.

The movement may be magnified in many ways. This may be expanded and a liquid column moved altering the pressure etc.

May 1, 1901

From old notes

Considerations regarding transmission without wires to great distances by my system

Take following data:

Capacity of an elevated terminal (at some distance above ground, enough to have most of charge "free") to be 10^5 cm. Assume electrical movement to amount **apparently** to a rate of 5 (five) million Horse Power, 3 – 4 cycles per second the rate of vibration.

We have $5\,000\,000 \times 750 = \frac{1}{2} V^2 \frac{10^5}{9 \times 10^{11}} \cdot 40$; $p = 40$ approx. From this we get $V = 40,000\,000$ Volts approximately. This would be necessary to charge capacity with for producing movement assumed of 5×10^6 H.P.

Taking now capacity of Earth $9 \times 10^5 \times 720$ cm, each potential variation max. per half cycle will be $\frac{10^5}{9 \times 10^5 \times 720} \times 4 \times 10^7 = 6000$ Volts. Suppose now an other plate of 10^5 cm be used at distant station how much energy could be received? Energy will be $= \frac{1}{2} \times \frac{10^5}{9 \times 10^{11}} \cdot 36 \times 10^6 \times 40 = 80$ Watts. But the apparent energy could be magnified greatly by resonance at best 100 times. Hence 8000 apparent Watts could be obtained. From this clear that transmission of a signal **even** to a planet possible.

May 4, 1901

483

Readjustment of laboratory apparatus

Large coil № 16 Oconite wire in center of room.

Fundamental tone obtained with

4 jars in each condenser set

$2\frac{3}{4}$ turns in Selfind. Regul.

Green coil for physiological effects:

Fundamental tone

4 jars in each condenser set

$7\frac{1}{2}$ turns in Self. Regul.

Coil with handle brass for lighting tubes in hand etc.

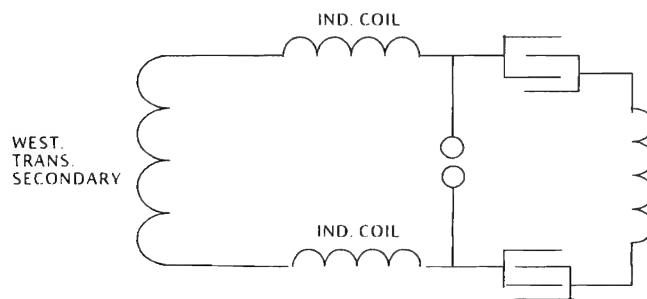
4 jars in each condenser set

20 turns in Self. Regul.

Note. A curious observation was made when cable around room was energized very shortly. The cable was bent into a circular loop to serve for room experiments. When a large loop with miniature incandescent lamp was held horizontally in the room the miniature lamp lightened up strongly. When holding the loop in a vertical plane, parallel to the plane of loop of cable and **not far** from same the lamp did **not** light up as strong although theoretically it should have received much more energy. This is very curious particularly because effect observable only with very strong excitation of cable or loop.

May 10, 1901

Approximate estimate of inductance coils to be used in series with Westinghouse transformer for charging the condensers in laboratory apparatus.



Two spools are made 19" outside diam.

5" smallest diam. (core)

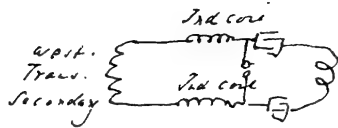
Width of coils $2\frac{1}{2}$ ".

Taking 1000 makes and breaks per sec. on spark wheel this would correspond to cycles $500 = n$. To work with, we should have the inductance of the two coils to satisfy relation $2\pi n = \frac{1}{\sqrt{LC}}$. We can take C approx. equal to capacity of 3 large jars = $0.03\mu\text{F}$. This would give for both coils inductance: $\frac{10}{3}$ Henry. Or each of the coils should have $\frac{10}{6}$ Henry = $\frac{10^{11}}{6}$ cm.

May. 10. 1901.



Approximate estimate of inductance coils to be used in series with Westinghouse transformer for charging the condensers in laboratory apparatus.



Two spools are each 19" outside diam.
5" smallest diam. (core)
width of coils 2 1/2"

Taking 1000 turns and breaks per sec. as standard this would correspond to cycles 500 = n . To work well we should have the inductance of the two coils L satisfy relation $2\pi n = \frac{1}{\sqrt{LC}}$. We can take C approx equal to capacity of 3 large jars = 0.003 m.f. This would give for both coils inductance: $\frac{1}{6}$ Henry. Or each of coils should have $\frac{1}{12}$ Henry = $\frac{10^{-10}}{6}$ c.m.

Call length of each layer l , n_1 number of turns per layer n_2 number of layers, a smallest area, A largest area. Then inductance of smallest coil $L_1 = \frac{4\pi a n_1^2 l}{l}$

$$L_2 = \frac{4\pi a n_1^2 l}{l}$$

$$L_{n_2} = \frac{4\pi A n_1^2 l}{l}$$

$$\text{Total will be } L = \frac{4\pi n_1^2}{l} (a + a_1 + \dots + A) = \frac{4\pi n_1^2}{l} \cdot \frac{n_2}{2} (a + A) = \frac{2\pi n_1^2 n_2 (a + A)}{l}$$

Since all the turns are superimposed the actual inductance - when all coils are instead of being separated together - will be approximately $\frac{1}{2}$ times greater. Hence the inductance (actual) will be not far from

$$L_1 = \frac{2\pi n_1^2 n_2 (a + A)}{l} \text{ from this formula}$$

we can now determine the number of turns and layers.

$$n_1 n_2 = \frac{L_1 l}{2\pi (a + A)}$$

$$\text{Here } L_1 = \frac{10^{-10}}{6} \text{ H} = \frac{10^{-10}}{6} \text{ c.m.}$$

$$l = 2\frac{1}{2}'' - \frac{1}{4}'' - \frac{1}{4}'' = 2'' = 5 \text{ c.m.}$$

Now n_2 is a fraction of n

$$a + A = 1906 \text{ c.m. } 2\pi(a + A) = 12284$$

$$\text{Hence } n_1 n_2 = \frac{\frac{10^{-10}}{6} \cdot 5}{12284} = \frac{10^{-10}}{73704} = \frac{10^4}{737} = 136 \times 10^3$$

1)

Call length of each layer l , n_1 number of turns per layer, n_2 number of layers, a smallest area, A largest area. Then inductance of smallest coil,

$$L_1 = \frac{4\pi a n_1^2}{l},$$

$$L_2 = \frac{4\pi a_1 n_1^2}{l},$$

$$L_{n_2} = \frac{4\pi A n_1^2}{l}.$$

$$\text{Total will be } L = \frac{4\pi n_1^2}{l}(a + a_1 + \dots + A) = \frac{4\pi n_1^2}{l} \cdot \frac{n_2}{2}(a + A) = \frac{2\pi n_1^2 n_2 (a + A)}{l}.$$

Since all the turns are superimposed the actual inductance – when all coils are instead of being separated together – will be approximately l times greater. Hence the inductance (actual) will be not far from

$$L_1 = 2\pi n_1^2 n_2 (a + A).$$

From this formula we can determine the number of turns and layers.

$$n_1^2 n_2 = \frac{L_1}{2\pi(a + A)}. \text{ Now } n_2 \text{ is a function of } n. a + A = 1956 \text{ cm}, 2\pi(a + A) = 12284$$

$$\text{Here } L_1 = \frac{10}{6} \text{ H} = \frac{10^{10}}{6} \text{ cm}, l = 2\frac{1}{2}'' - \frac{1}{4}'' - \frac{1}{4}'' = 2'' = 5 \text{ cm}.$$

$$\text{Hence } n_1^2 n_2 = \frac{10^{10}}{6} \cdot \frac{1}{12284} = \frac{10^{10}}{73700} = \frac{10^8}{737} = 136 \times 10^3.$$

To carry the current № 20 wire should be used. This will give 45 turns per layer. Take average insulation between layers $\frac{1}{32}''$.

$$\text{Now from above: } n_2 n_1^2 = 136 \times 10^3, n_2 = \frac{136 \times 10^3}{n_1^2} = \frac{136 \times 10^3}{45^2} = \frac{136 \times 10^3}{2025}.$$

$$n_2 = \text{approx. 67 layers.}$$

Now we get for 2" 45 turns.

The outer diam. of spools is 19", inner diam. 5". Space for wire 7". Of this we must deduct say $\frac{68}{32} = 2.12''$ for insul. Would give more layers than necessary. Hence we may take wire thicker.

Assume № 18 wire. Comes out still too much.

With № 16 we get 31 turn per layer that is ... Take length 2". This would make

$$n_2 = \frac{136 \times 10^3}{31 \times 31} = 140 \text{ layers that is too much}$$

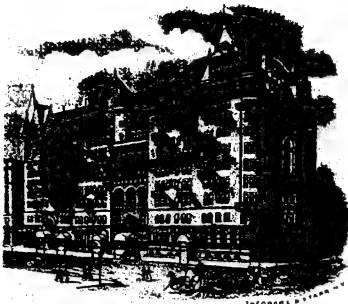
Take again wire № 18. For layer 42 turns. $n_2 = 136000 : 1764 = 77$ layers. As a matter of fact more layers ought to be put on. Therefore wire № 18 will probably suit. 96 layers can go on in space. By using insulation slightly thicker about 80 layers can be put on. This will do. This will make total turns 3360 turns. Length of wire approx. = over 10 000 feet in each coil. We want more than 20 000 feet for both or over 100 lbs. Order 120 lbs at once.

May 19, 1901

From old notes

In many instances when working with an oscillatory system transmitting its vibrations upon the ground I observed that the effects produced were stronger when the oscillating system was connected to earth through a condenser. This may have been due to some secondary causes but theoretically there are reasons for expecting such a result.

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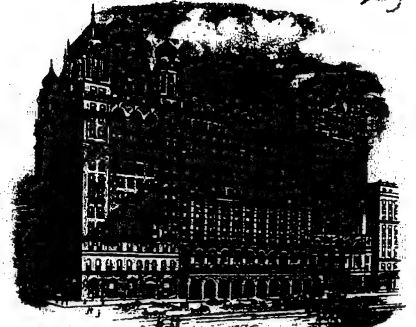


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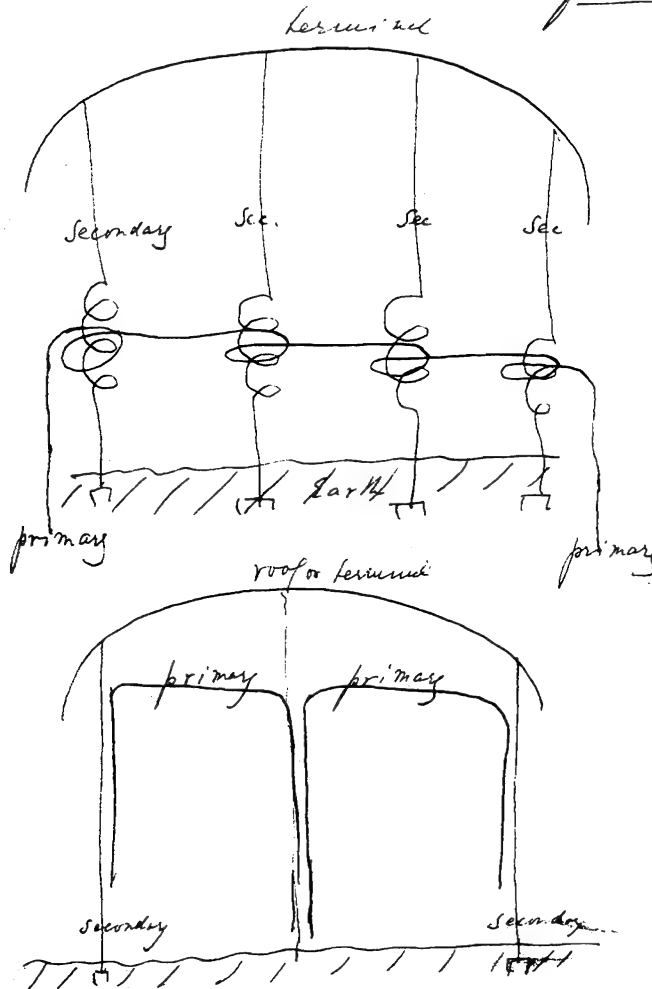
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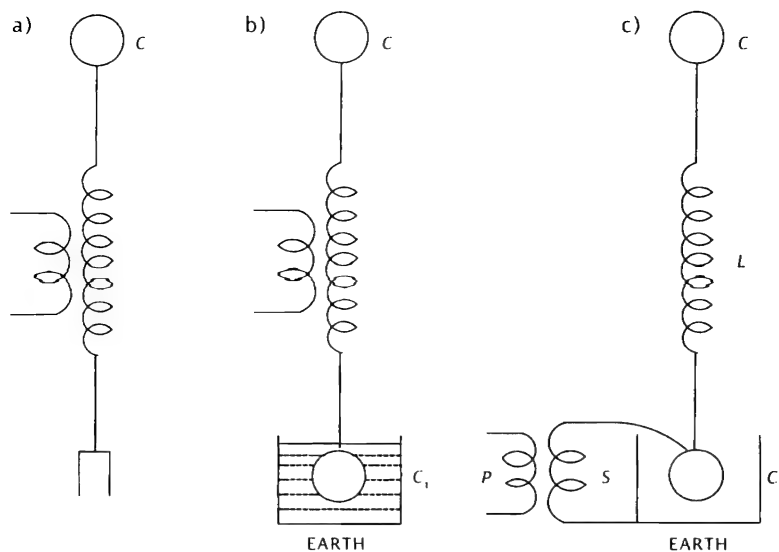
THE ASTORIA

New York May 19 1901
from old notes



This arrangement may be resorted to to as to make insulation of terminal in my system unnecessary. The support of a roof may be of metal and currents may be induced in them through primary discharges & currents.

The second arrangement will permit the use of straight metallic supports. In some cases it may be practicable though not highly economical.

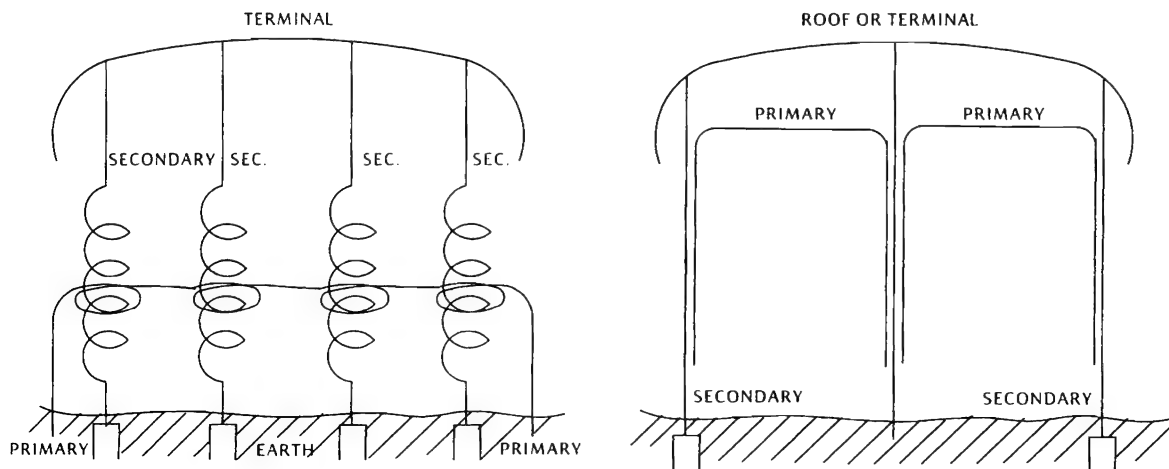


a illustrates the older arrangement, *b* the modified plan with condenser C_1 . It would seem that in case *b* a more vigorous vibration can take place in system because it is left to itself and not intimately connected to ground. The damping factor might be smaller in case *b*.

In fig. *c* the most effective plan is illustrated. Here the secondary *S* is joined to the condenser C_1 . When $C = C_1$, the length of oscillating condenser or coil *L* should be $\frac{1}{2}$ of the wave length.

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From old notes

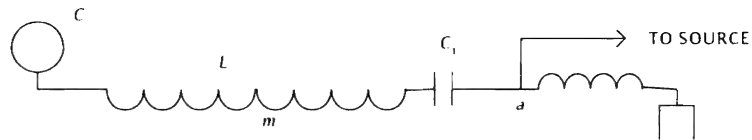


This arrangement may be resorted to so as to make insulation of terminal in my system unnecessary. The supports of a roof may be of metal and currents may be induced in them through primary discharges or currents.

The second arrangement will permit the use of straight metallic supports. In some cases it may be practicable, though not highly economical.

The following plan has been found convenient in the determination of capacities as that of an insulated terminal or of a coil by resonance method as described in Colorado Notes.

The coil L is excited in any of the ways previously described, for instance by connecting a point a to a source of the oscillations. When C is equal C_1 then the neutral point m is just at the middle of the coil. The capacity C_1 is easily calculated or determined. The greater C_1 as compared with C the more the point m shifts towards C_1 . Interesting measurements may be made in this manner. There are a number of ways of locating the point m . A minute spark gap is the simplest means. When C_1 is connected to earth then m falls together with one of the coatings of C_1 , at least practically so.



When a terminal is used in the form of a metallic surface on roof supported on metallic bars or pipes or any conducting supports the difficulty arises to get the vibration quick enough. Even if the roof be large owing to the small inductance of supports the vibration is still very quick and for many purposes as signalling without wires to great distances unsuitable.

Following plan may be very good:

I propose to construct a roof in the form of a spiral of metal sheet (copper) (or aluminium) so that it forms a solid structure but with turns insulated from each other. The insulation may be porcelain or glass. Blocks of such material may be cast in proper shapes so as to render construction of roof cheap and easy. The turns of the spiral roof would lay horizontally and would be wound around a larger central terminal and the whole supported on conducting supports buried with their lower ends in the ground. Into the terminal in center a resonating high tension circuit may discharge causing the system to oscillate.

Several constructions to follow.

— . —

Suppose we attempted to transmit a message to a planet as Mars by rhythmical variation of the potential of Earth through a powerful oscillator. Take area of one coating of the condenser constituted by the planet Earth and intervening dielectric $A = 32 \times 10^{16}$ sq. cm

Assume distance to be greatest 64×10^{11} cm.

The minimum capacity would be $C_{\min} = \frac{32 \times 10^{16}}{4\pi \times 64 \times 10^{11}} = 4000$ cm approximately.

If we now were to produce a variation of one volt 10 times per second the energy delivered per second would be

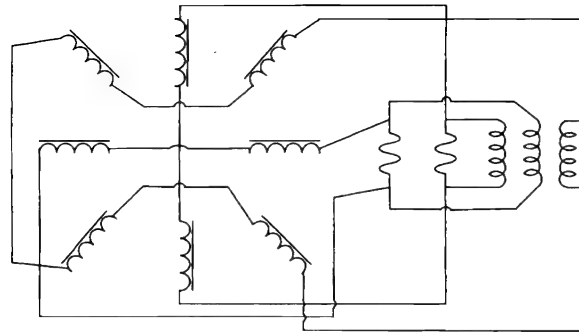
$$E = 10 \times \frac{1}{2} \cdot \frac{4000}{9 \times 10^{11}} = \frac{2}{9 \times 10^7} \text{ Watts. With 100 Volt we would have } \xi = \frac{2}{9000} \text{ Watts!}$$

Such a variation 10 times per second could be produced by my method easily.

— . —

Motor with great torque and no dead point

The following seems to be a very good way of constructing a motor of my system which will have advantages over the two phase as ordinarily constructed, also over three phase motor.



The general idea is to get the intermediate phases by cooperation of the two phase circuits. A transformer is used the secondary of which is energized by both the circuits. This gives 45 degrees for intermediate poles. The idea is applicable also to 3 phase motors.

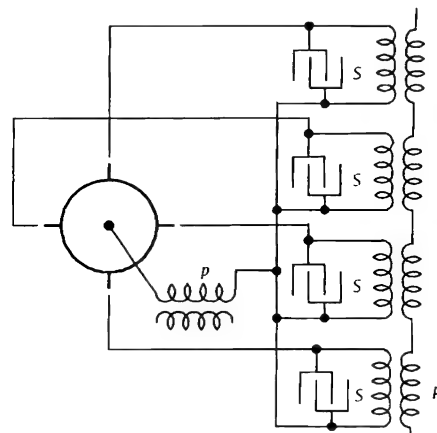
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May 24, 1901

Old arrangement with many spark gaps or make and breaks in multiple arc reconsidered.

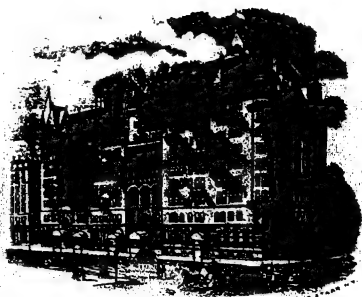
By using instead of one n spark gaps or make and breaks the current in each is $\frac{1}{n}$ of the total. The loss in each is $\left(\frac{1}{n}\right)^2$ and the total loss $\frac{1}{n}$ of that which would occur if all the current were passed through one arc. Theoretically with this arrangement the loss could be reduced as far as desired by simply augmenting the number of arcs.

With alternating current it is easy to use a number of transformers or one with many separated windings insulated from each other at least at one end. The connections are in the simplest way as indicated on diagram below.



Suppose there are four arcs all made in same moment. The advantage is that the loss will be only $\frac{1}{4}$ of that taking place in usual arrangement. The primary p may serve for all condensers or independent primaries may be used. The sketch shows the idea applied to my system and it is generally applicable. Various dispositions to be shown.

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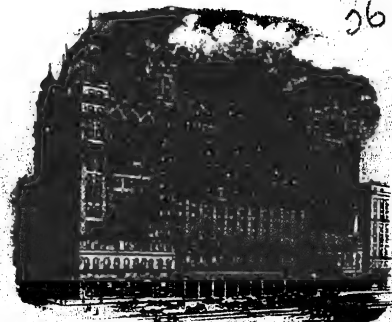
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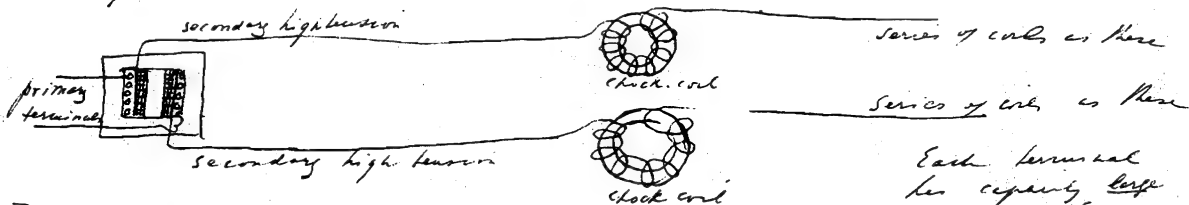


THE ASTORIA

New York May 26 1901

from old notes

Producing high e.m.f. from ordinary alternating currents
in the transformers and choking coils.
Arrangement as in sketch or similar:



The currents in such a system with resonating
conditions will be large and therefore
it may be very great certainly not less than 1000.

Now L of each of the choking coils

$$L = \frac{4\pi \cdot N^2 \cdot A}{l \times 10^9}$$

The individual coils should be small
so that they may be connected in series.
If they are large the spark would break through to the iron core.
Let $A = 10$ c.m.² $l = 10$ c.m. $N = 500$ Then $L = \frac{12.6 \times 20 \times 10^4 \times 10}{10^{10}} \cdot 10^3$
 $= 0.126 \times 20 = 2.52$

Suppose 4 coils in the 180 cycles per sec.

Let capacity at end of each terminal be 1000 c.m. say $L = 3$ Henry.
Assume further secondary connected to ground in middle. Then there would be two circuits
a number of coils in each circuit or branch, & capacity
at each terminal. Self-induction of secondary neglected
also capacity of wire for present.

and: $\frac{1}{100} = \frac{25}{100} \sqrt{L \cdot C}$
from this $n = 444$ coils.

1.

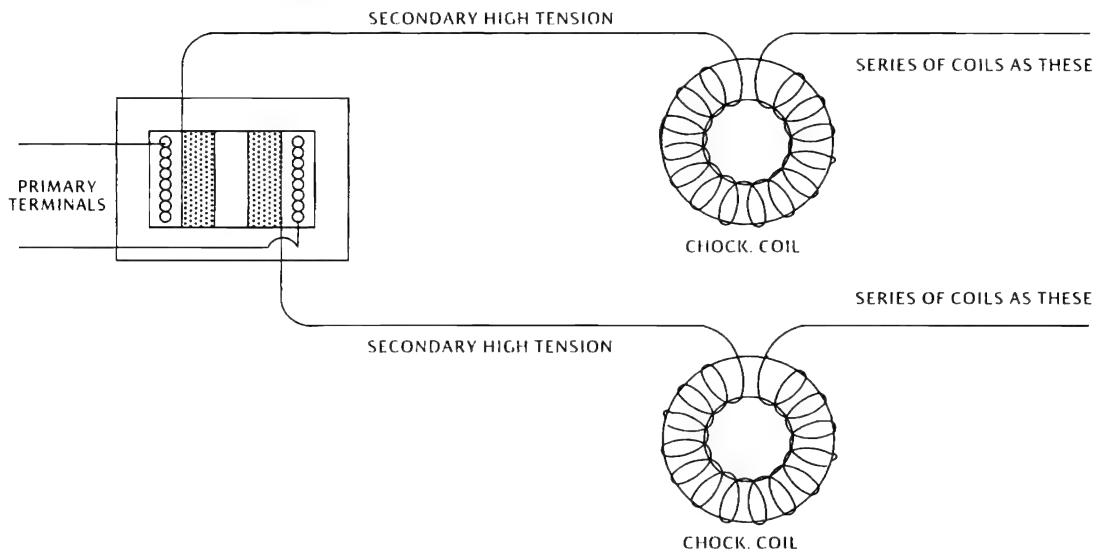
Several windings, sources or induction apparatus arranged to discharge through gaps or make and breaks. The oscillation started in one of them, spark or break bridged. Current now induced in an other element and spark in that element bridged and so on. This forms a direct current system. Oscillation may be started and the discharges will pass through the gaps or make and breaks automatically. Many ways of carrying out the idea obvious. Will be shown in subsequent sketches.

May 26, 1901

From old notes

Producing high e.m.f. from ordinary alternating circuits with transformers and choking coils.

Arrangement as in sketch or similar:



Each terminal has capacity large on end. Say spheres or insulated cylinders, roofs etc.

The currents in such a system with resonating conditions maintained are large and therefore μ may be very great, certainly not less than 1000

Now L of each of the choking coils $L = \frac{4\pi \cdot N^2 A}{l \times 10^9} \mu$. The individual choking coils should be small so that they may withstand the stress. If they were large the spark would break through to the iron core.

Take $A = 10$ cm sq. $l = 10$ cm, $N = 500$. Then $L = \frac{12.6 \times 25 \times 10^4 \times 10}{10^{10}} \cdot 10^3 = 0.126 \times 25 = 3.15$. Say $L = 3$ Henry

Suppose we work with 130 cycles per sec. Let capacity at end of each terminal be 1000 cm. Assume further secondary connected to ground in middle then there would be two circuits and: $\frac{1}{100} = \frac{2\pi}{10^3} \sqrt{nLC}$; n = number of coils in each circuit or branch, C = capacity on each terminal. Self-induction of secondary neglected, also capacity of wire for present.

If both branches constitute one circuit this would mean that there would be 444 coils in all or 222 in each leg.

The above estimate is rough but shows clearly that under above assumptions it would be hardly practicable to use such apparatus.

We should have higher frequency, more turns in each choking coil and greater capacity on end.

We may use as terminals horizontal roof with rounded ends (toroidal form) large radius of curvature to withstand high pressure. The capacity of such terminal if not at great altitude may be considerable. We can get very easily 10 000 cm. By using finer wire in coils we can have in each 1000 turns. Then the inductance of each will be above 12 Henry. For the same frequency as before we would then have n_1 number of coils:

$$\frac{1}{130} = \frac{2\pi}{10^3} \sqrt{n_1 \cdot 12 \times \frac{10000}{9 \times 10^5}} \quad n_1 = 11 \text{ coils nearly.}$$
 This would be thoroughly practicable. The coils could be oil insulated. One terminal connected always to core and oil tank and only one terminal insulated and led to next tank core and terminal etc.

We may now consider what under above conditions might be expected from apparatus. To get 1000 turns in each coil we should have to use wire № 22 perhaps silk insulated.

1000 turns will have length approx. of: $1000 \times 8 = 8000 \text{ inch} = 750 \text{ feet.}$

Assume 6 coils in each leg, that is 12 coils total, we would then have total length of wire in choking coils: $12 \times 750 = 9000 \text{ feet.}$

The resistance would be: 62 feet per Ohm $9000 : 62 = 145 \text{ Ohm.}$

Suppose total resistance of circuit to be 200 Ohm. Neglecting for the moment hysteresis and other frictional losses we would have E at the terminals:

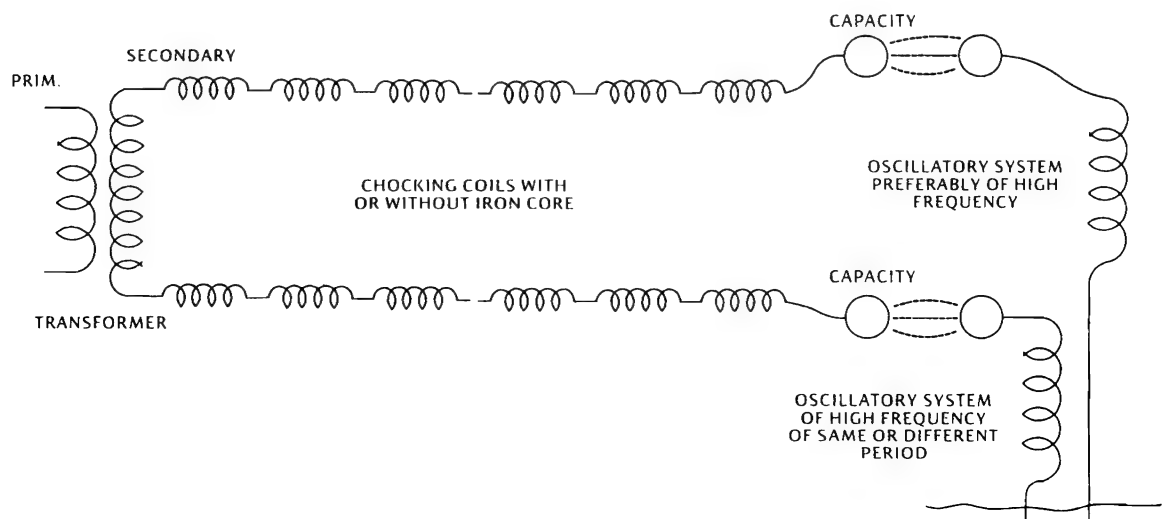
$$E = e \cdot \frac{Lp}{R}$$

e initial e.m.f. at the terminals of exciting transformer.
 $L = 12 \times 12 = 144 \text{ Henry.}$
 $p = 2\pi n = 820 \text{ approx. } R = 200.$
 say approximately the e.m.f. initial will be raised to 500 times the value

$$E = e \cdot \frac{144 \times 820}{200} = 580 \cdot e$$

Now e can be under above conditions easily 10000 Volts judging from the number of turns the secondary might have with resistance assumed. Hence $e = 500 \times 10000 = 5 \text{ million Volts.}$

Summing up preceding results show that it is practicable to raise the e.m.f. in the manner for many purposes. For example in telegraphy without wires a high pressure may be in this way attained and by discharging the capacity or capacities at the terminal or terminals of the system into an other system strong effects may be secured without the necessity of converting to high frequency currents first. A scheme of this kind is illustrated below:



In this case the energy accumulated in the resonating circuit will be suddenly discharged and causes high frequency oscillations in the two system in accordance with my method. The both systems may be of same period or of different as described in my patent At the receiving station the receiver may be operated by one vibration or two. In similar manner more circuits may be provided. This scheme is simple and good.

May 29, 1901

From old notes Oct. 1900

Various ways of controlling oscillators or vibrating currents in general. The chief question involved in the various plans is to control with the miniature effort great movements of electricity. This is a broad important idea and great triumphs will be achieved in many directions by delicate control of strong effects. This is practically important in connection with telephony without wires also in telegraphy over great distances as I soon contemplate to carry out.

Following ways of controlling oscillators have been experimented upon:

a) varying the intensity of oscillations produced; b) varying period and thereby destroying resonating conditions (very sensitive); c) shunting primary exciting current or circuit and varying resistance or impedance of shunt; d) double wound vibrating circuit employed and period in one of the windings varied (excellent results); e) various ways of utilizing heating effects of receiving station which are to be separately described. In some cases spark reproduced and an other transmitter set in action.

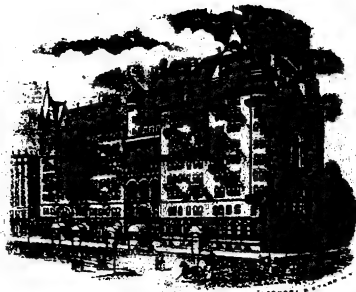
- f) Various electrodynamic effects to be separately described.
- g) Bridge arrangement with resistances excellent in its results.
- h) Bridge arrangement with condenser in secondary receiving circuit **very sensitive**.
- i) Various arrangements with condensers in transmitting and receiving circuit to be described.
- j) Arc of oscillator primary to secondary controlled by air compressed. Control of valve delicate.
- k) Auxiliary small arc controlled at transmitting end. Arc to ground controlled excellent.
- l) Condenser connection controlled impedance or resistance of same in many ways.
- m) Several dead beat arrangements when condenser method used at receiving end.
- n) Various ways of using batteries with condensers for control etc.

A very excellent idea is to cause a shifting of maxima and minima points along a conductor and effect control of other useful performances in this way. There are great many ways in which this idea may be applied. A condenser may be charged from the circuit by tapering same at one or more (two) points and great sensitiveness can be secured by using the energy of the condenser in receiving circuit. Slight displacements of the maxima and minima will cause great variations in the energy and in this way also a transmitter can be controlled by slight effort. This is to be separately treated.

A good way is to use a spark gap which is so arranged that by any change in it points of maxim. and min. are shifted. The arc may be controlled by voice. This is capable of great sensitiveness. In this way Roentgen rays and ultraviolet rays and similar radiations may be controlled or utilized. These rays themselves enable the control. This to be separately dealt with.

In telephony as well as telegraphy through media natural it is very good to have independent oscillating circuit connected to ground through a condenser and effect variations of capacity of latter. Also very good to alter period of impressed vibrations or otherwise destroy harmony thus varying effect. The freely vibrating circuit may be of low period and tuned to average of voice undulation. A very

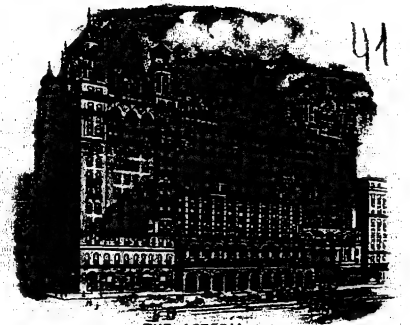
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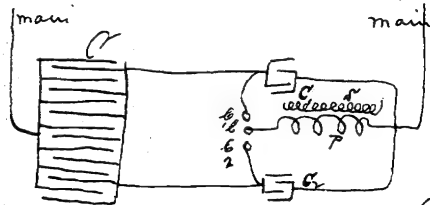


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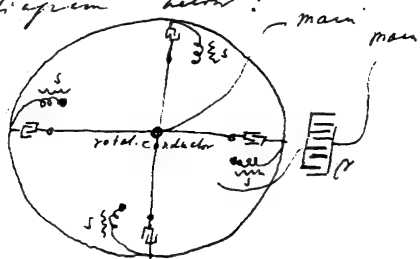
New York May 29 1901

from old notes of experiments.

In order to improve oscillatory apparatus arrangements as below illustrated were experimented with:



of a large condenser supplied from direct current generator of 220-500 volts. Higher tension would have been preferable. Or, or smaller condensers. E. G. break gaps effected by mercury as in my breaks. It was found in this arrangement break points can be close. No arcing. The condenser prevents short-circuit effects. For many purposes this scheme is excellent. An improvement was effected by using great many small condensers. The condensers C_1, C_2, \dots, C_n . In one case 24 condensers were used. The condensers are discharged successively through the same primary. The apparatus worked very well but output is comparatively small. The machine was subsequently modified and instead of one many primaries used, one for each condenser. The secondary were connected in series. Also in multiple they may be connected under various conditions. The scheme of connections is shown in diagram below:

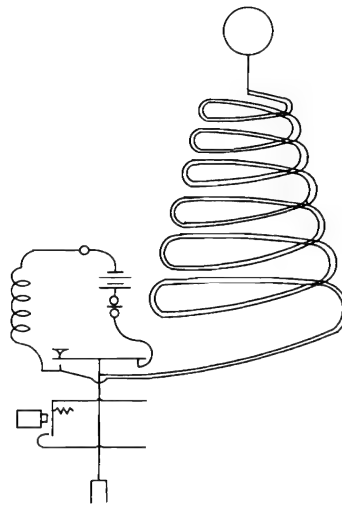


Only from condensers and primaries are shown. The secondaries SSSS may be used separately or any number of them connected together. The condenser C must be charge large as it is charged and discharged completely only twice by one complete revolution of rotating discharging conductor.

long lever light moved by diaphragm seems very good. Continue to investigate. Two primary windings oppositely wound and one shunted. By controlling impedance of shunt small variations are made to produce great changes. Very good.

From old notes

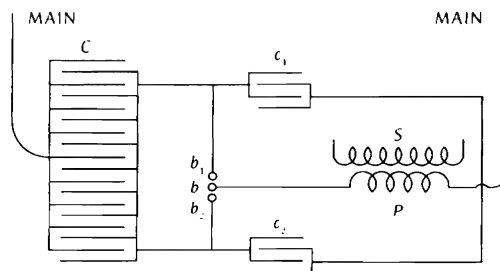
Following was found to be an excellent arrangement in signalling without wires suitable both for transmitter and receiver circuit. In the former great variations of intensity should be produced by small variations in the action of controlling device. This is particularly important in telephony. In the receiver, however, when using a secondary it is difficult to utilize economically the energy received in primary from distant transmitter. The scheme illustrated offers in this connection great advantages. The diagram shows connections as have been used sometimes in telegraphy.



The idea is as before illustrated to use two circuits placed close together and effect variation by disturbing resonating balance. When one of the circuits is but slightly quickened or retarded great changes in the intensity of signals transmitted are produced because chiefly of large capacity effect of adjacent turns. So at least I explain great sensitiveness. This makes evident the effectiveness of transmitter. On the receiver station one of the conductors is used as secondary that is only one of the circuits or conductors receives effectively the oscillations through the ground. As the circuits are very close throughout their extent the transformation is economical. Particularly good is in this connection a concentric cable the inner wire serving as secondary being very thin so as not to impair resonant rise. Various arrangements of this kind with telegraphic and telephonic apparatus are to be shown.

From old notes of experiments

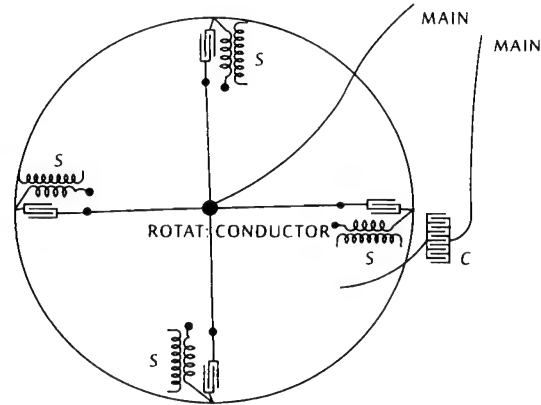
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C a large condenser supplied from direct current generator of 220–500 Volts. Higher tension would have been preferable. C_1, C_2 smaller condensers. b_1, b_2 break generation effected by mercury as in my breaks.

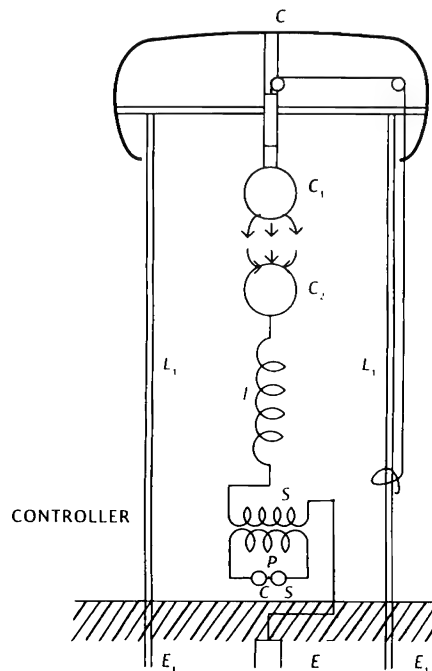
It was found in this arrangement break points can be close. No arcing. The condenser C prevents short-circuit effects. For many purposes this scheme is excellent. An improvement was effected by using great many small condensers, C_1, C_2, \dots, C_n . In one case 24 condensers were used. The condensers are discharged successively through the same primary. The apparatus worked very well but output is comparatively small.

The machine was subsequently modified and instead of one many primaries used, one for each condenser. The secondaries were connected in series. Also in multiple they may be connected under certain conditions. The scheme of connections is obvious in diagram below:



Only four condensers and primaries are shown. The secondaries $ssss$ may be used separately or any number of them connected together. The condenser C must be always large as it is charged and discharged completely only twice by one complete revolution of rotating discharging conductor.

From old notes



In annexed sketch a terminal C in form of a roof is supported on conducting supports L_1, L_2 . Terminal C_1 is adjustable and in contact with structure of roof or terminal C . A resonating system C_2, L_2, E_1, E_2 discharges into C_1 and produces oscillations in system CL_1, L_1, E_1, E_2 . This arrangement obviates necessity to support roof or terminal C on insulated supports.

Now in a sketch the difficulty will be probably to get the oscillations of the free system CL_1, L_1, E_1, E_2 slow enough to be very effective in transmission through Earth as in my system. The length of conductors in the free system should be $\frac{\lambda}{4}$, and the length of the discharging circuit should be $\frac{3}{4}\lambda$ or $\frac{n}{4}\lambda$ eventually, n being uneven number. Suppose to get an idea we take $C = 10000$ cm. This is realizable. Then we have $\frac{2\pi}{10^3} \sqrt{L \times \frac{10000}{9 \times 10^5}}$ the period of system. We should have vibration not much quicker than 100 000 and to satisfy this L would have to be : $\frac{1}{100000} = \frac{2\pi}{10^3} \sqrt{\frac{L}{90}} ; L = \frac{9 \times 10^5}{4} = 225000C$.

Calculated it would appear that the supports L would have to be about 600 feet. The arrangement would be o.k. with quick oscillations. The self-induction of a straight conductor is $L' = r l' (\log_e \frac{2l'}{r} - 0.75)$. Now, take $L' = 300$ feet = 9000 cm. If we have to use iron pipes 4" diam. $r = 5$ cm. Then $\frac{2l'}{r} = 3600$ and from this I find $L' = 134000$ cm. Again taking the length 600 feet we would get inductance probably 268 000 cm. To get lower frequencies evidently in above scheme self-induction must be increased. The charging and discharge circuit may also be of different period and both vibrations used to excite receiver.

May 30, 1901

Previous calculation decidedly shows that we can expect 1) to store 1000 Watts in condenser primary per charge 2) that condenser can be charged and discharged 5000 times per second. This ignores all losses so far. Primary rate would be limited to one discharge and so also secondary rate without further provision. But if discharges fall together and are all added up, then secondary rate determined by 1) duration 2) by Ohmic etc. loss.

Suppose then 1000 Watts stored charges and discharges 5000 times.

The rate will have to be reduced first of all to one half because of intermissions necessary for charging. This might be overcome by a number of condensers 2 or more which are charged and discharged alternately. But with one condenser evidently primary rate can not be more than 2,500,000 Watt rate during the intervals of charges while the break is working. This too is by far too high.

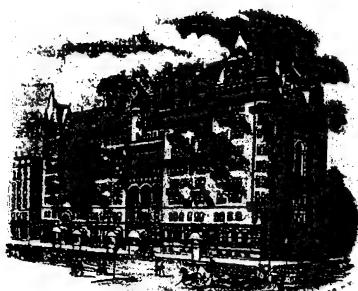
The losses in the arc etc. must bring this rate down to one half. Conservatively estimated we can not transfer to the secondary more than 1,000,000 Watt rate. The mechanical system does not limit, nor the capacity of the condenser for storing and giving off. During signalling energy may be taken off for $\frac{1}{30}$ of a second if necessary. We may take $\frac{1}{5}$ of second then the total energy accumulated in secondary swinging system will be $\frac{1}{2} CP^2 = \frac{10^6}{50} = 20000$ Watt. Hence with $C = 1000$ cm, $p^2 = 40000 \times 9 \times 10^8$, $P = 6 \times 10^6$ Volts.

— . —

Transmission to a distance through wires or conductors of writing, print, pictures or images. Also "seeing by wire".

Method of and apparatus for same.

The broad idea underlying the invention is to enable a condition – similar in many respects to that existing in the eye and optic nerve – to be attained. There must be a definite relation as to order

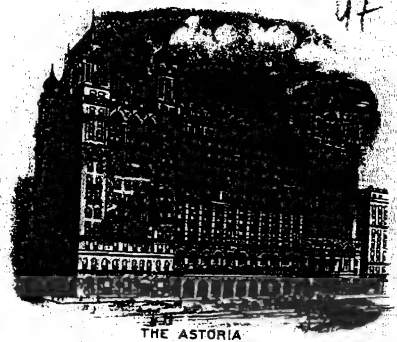


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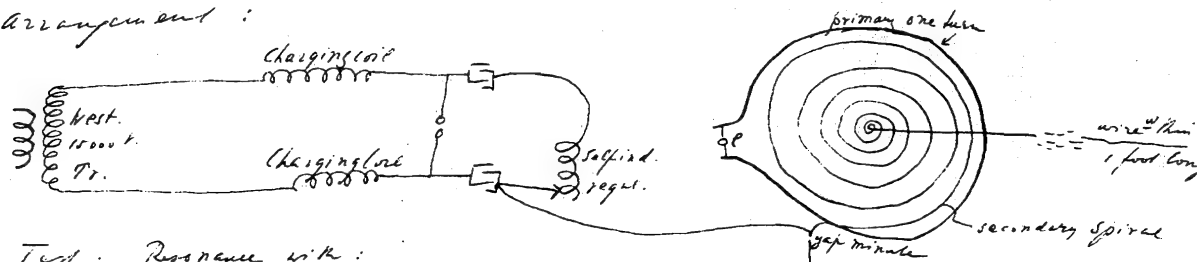
THE ASTORIA

New York June 1, 1901

Determination of vibrations of Laboratory apparatus.

Large secondary spiral wound on frame 8x8 feet with #8 outer turns coil #8 inner turns with Okonite insulation thick.

Arrangement:



Test: Resonance with:

Capacity 6 jars in each condenser set
Inductance Connections + 6 5/16 turns

Same set with small loop in secondary

Then I think preferable to former method with a gap in the coil to be more easily.

Test shown Resonance with:

Capacity 6 jars in each condenser set
Inductance Connections + 7 turns in self-inductance box.

There is an objectionable feature in both these methods of testing although they are good. Namely, the system to be tested should be connected to ground. The e.m.f. necessary for excitation obtained by induction. I propose to employ small coil of thick wire in ground connection and induce in the same the e.m.f. necessary.

and intensity between numerous channels, fibres or nerves of the transmitter and receiver. I use for this purpose tuned circuits and by methods and apparatus already described it is easy to provide any number which may be required. Taking only a few fundamental notes a great number of combinational effects may be obtained, comparable to those involved in vision as to number. Now the eye receives rays and these propagating in straight lines necessarily retain their order and relation in space. But in transmitting impulses through a wire for example all currents will pass through same channels and not in fibres or bundles separated from each other. Nevertheless a result for all practical purposes the same as in the transmission of light images by rays can be obtained by arranging the transmitting and receiving circuits in the same order. Although the impulses will pass through the wire without preserving order yet inasmuch as they are again singled out and separated in the same order as sent from transmitter it is evident that by such means images pictures etc. in fact knowledge of forms can be conveyed.

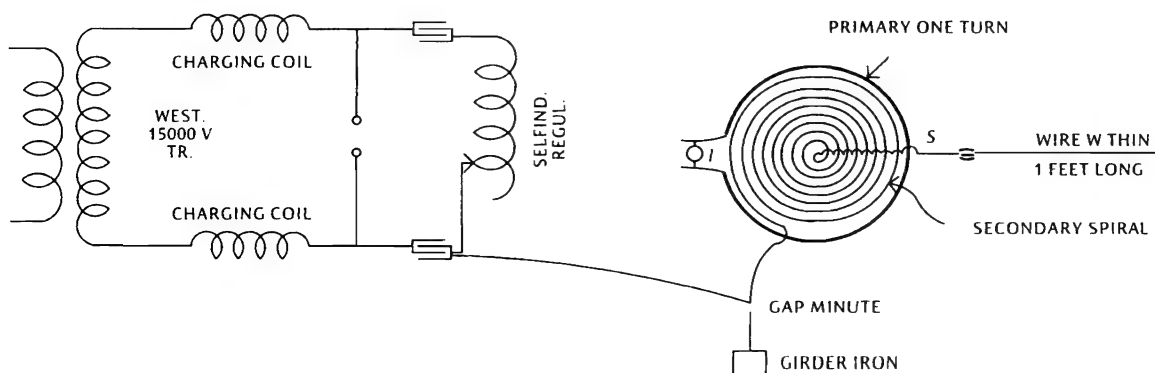
To this I referred in article in "Colliers weekly". The best way now known to me to carry out the invention is to provide a transmitting and a controlling plate comprising numerous separate and insulated points close together as to form a surface practically uniform. The separate elements of this surface or plate are to be cells of selenium in the picture transmission. The elements could form little squares or hexagons preferably. The individual cells of selenium will control such a transmitting circuit tuned or individualized by my methods. When an image is projected upon the surface consisting of these cells the corresponding transmitter will be set in action. The control by means of the cells of these transmitting circuits should be such as to produce variations of density in the oscillations proportionate to the action on the cells. At the receiving end there will be receiving circuits or elements each corresponding to one of the transmitting circuits. The receiving circuits will be in any way connected with an apparatus comprising elements similarly arranged as in transmitter to form a plate or surface. Now there are great many ways of producing on paper an impression or image from the plate so constituted. The image must resemble the picture projected on the transmitter plate because the receiver plate is composed of elements arranged in same manner. Effects of color will enable the production of an image. By this method and apparatus transmission of images is certainly practicable. As to transmission of characters it is easy. In this case the selenium cells are not necessary for the control of the transmitting elements can be effected by contact for instance. No synchronous movement in this!!

June 1, 1901.

Determination of vibrations of laboratory apparatus

Large secondary spiral wound on frame 8x8 feet, wire N^o 8 outer turns cord N^o 8 inner turns both Okonite insulation thick.

Arrangement:



Test: Resonance with:

Capacity 6 jars in each condenser set
Inductance Connections + $6\frac{5}{16}$ turns

} Spark to ground was very small, $\frac{1}{32}$ "
to wire w 1"
(should have been greater, I think)

Same but with small lamp / in secondary

This I think preferable to former method. With a spark one is apt to error more easily.

Test showed resonance with:

Capacity 6 jars in each condenser set

Inductance Connections + 7 turns in Selfind. box.

There is in objectionable feature in both these methods of testing although they are good. Namely, the system to be tested should be connected to ground. The e.m.f. necessary for excitation obtained by induction. I propose to employ small coil of thick wire in ground connection and induce in the same the e.m.f. necessary.

"Extra" coil used in connection with spiral secondary wound with Rubber wire.

Same test as with spiral coil with spark analyzer as before:

Resonance obtained with

Capacity 6 jars in each condenser set
Inductance Connections + 2 turns in Ind. Regul.

} Spark to ground a little
over $\frac{1}{32}$ ", strong;
Spark to wire w $\frac{5}{8}$ "

Test with miniature lamp connected to sparking rim of coil on bottom showed resonance with:

Capacity as before
Inductance Conn. + $2\frac{1}{8}$ * turns in Regulator

} * This shows also as above
that vibration slower in test
with lamp slightly

A test was now made with big spiral again but with a vibration such as would make the length of spiral $\frac{3}{4} \lambda$. Rough computation showed that only one jar in each condenser set could be used making vibrations 2-4 times quicker. By taking out self-induction resonance was obtained with lamp:

Capacity one jar in each set of condensers
Inductance Conn. + $1\frac{1}{16}$ turns in Self. Regul.

} spark to structure very small,
almost touching electrodes

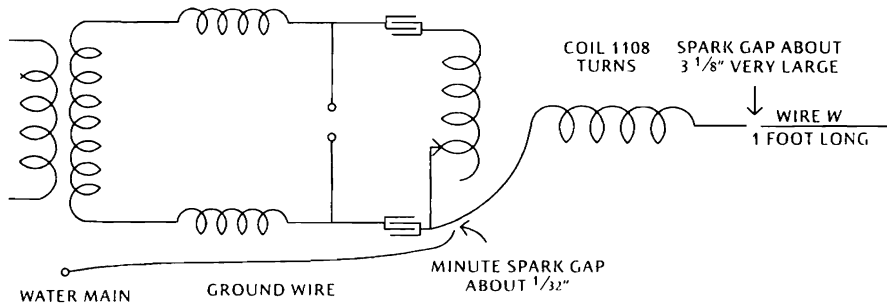
Test with spark analyzer showed resonance with about same turns in Regulator. An other tone was sought and resonance obtained with $5\frac{1}{2}$ turns in Regulator. The spark to iron girder was rather large: $\frac{3}{64}$ " about.

Effect of ground wire used in laboratory experiments ascertained:

For convenience in some experiments a ground wire № 8 cord is employed leading from apparatus along steam pipes to water main. The length of this wire is ... feet.

As this conductor adds to length of oscillatory system it has to be taken into consideration. To ascertain effect a coil was used of № 20 cotton covered bell wire, 1108 turns wound on wooden cylinder $3\frac{7}{8}$ " diam. $69\frac{3}{8}$ " long (wound part).

Arrangement first used:



Resonance was obtained with:
 4 jars in each set of condensers
 2⁵/₈ turns in Regul. Selfind.

In this test the ground wire added to the length of coil and made 1/4 wave longer, hence system responded to slower vibration.

Test modified with ground wire omitted and the small spark gap arranged on one of the iron girders. As the building is an iron structure of very large capacity even if there would be no ground connection we would get practically $\frac{\lambda}{4}$ for the length from small spark gap to larger on end of coil.

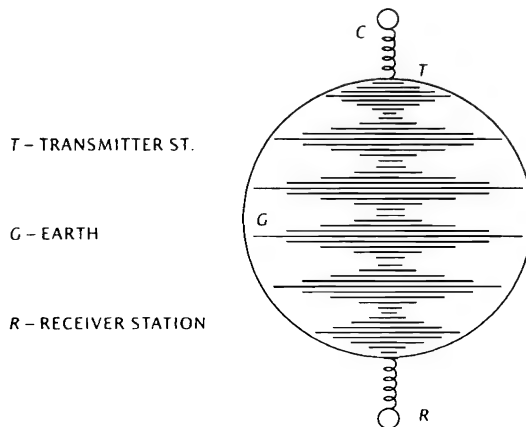
Test showed resonating conditions took place with:

4 jars in each condenser set
 2³/₁₆ turns in Regulating Selfind.

Note: In this experiment the coil had only 1100 turns which amounts for a slight quickening of the vibrations but not for the greater part of effect which was due to omission of ground wire.

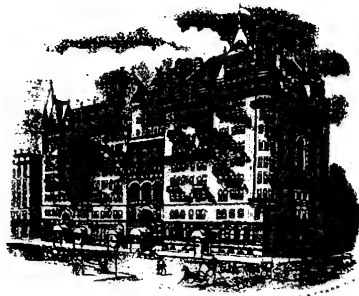
June 2, 1901

Transmission of electrical energy by conduction through Earth with my open synchronized circuits considered with reference to discovery of law of density



The experiments in Colorado seem to be conclusive in their proof that no appreciable loss of energy results in transmission under the conditions as illustrated in diagram, hence if we have a quantity Q of electricity in terminal at the transmitting station T the same quantity will distribute itself at

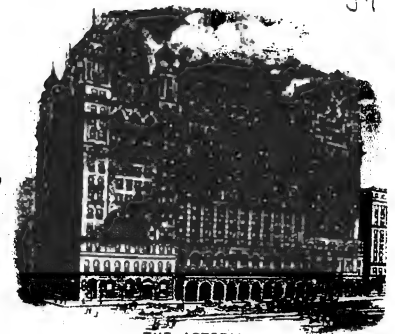
NEW YORK CABLE ADDRESS, BOLDT, NEW YORK
PHILADELPHIA CABLE ADDRESS, BOLDT, PHILADELPHIA



THE WALDORF
THE WALDORF ASTORIA, NEW YORK
HOTEL BELLEVUE PHILADELPHIA
THE STRATFORD, PHILADELPHIA
BULLITT BUILDING RESTAURANT, PHILADELPHIA
GEO. C. BOLDT, PROP.

The Waldorf-Astoria,

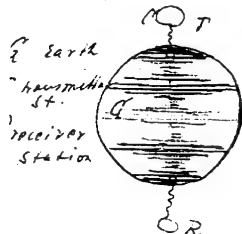
Fifth Avenue, 33rd and 34th Streets
and Astor Court.



THE ASTORIA

New York June 2 1911.

Transmission of electrical energy by conduction through earth with my open synchronized circuits considered with reference to discovery of loss of energy



The experiments in Colorado seem to be conclusive in their proof that no appreciable loss of energy results in transmission under the conditions as illustrated in diagram, hence if we have a quantity Q of electricity transmitted at the transmitting station T the same quantity will distribute itself at the opposite pole where receiving station is supposed to be located over an area covered by half of the world. An example will aid in giving an illustration of what can be reasonably expected in applying the principles for the above purpose. Suppose the capacity $C = 10,000$ (C.F.). This can be obtained by a roof insulated support. If the roof be say in the shape of a sphere (this will serve in the present example) it would have to have a radius of 100 meters. But since as demonstrated in my tests the capacity of these insulated terminals increases with elevation about $\frac{1}{2}\%$ per foot, by elevating sphere 400 feet only 33 meters radius will be all that is needed.

Assume now that 100,000 per second we adopted as frequency and that we expend on the generator 100 H.P. How much under best conditions can we expect to get at Receiving station? $100 \text{ H.P. roughly} = 71,000 \text{ Watts}$. This enables us to get pressure to which the insulated sphere or capacity C can be charged by this amount of energy.

1)

the opposite pole when receiving station is supposed to be located over an area covered by half of the wave. An example will aid in giving an illustration of what can be reasonably expected in applying the principles for the above purpose. Suppose the capacity $C = 10,000$ cm. This can be obtained by a roof on insulated supports. If the roof be say in the shape of a sphere (this will serve in the present example) it would have to have a radius of 100 meters. But since as demonstrated in many tests the capacity of these insulated terminals increases with elevation about $\frac{1}{2}\%$ per foot, by elevating sphere 400 feet only 33 meters radius will be all that is needed.

Assume now that 100 000 per second to be adopted as frequency and that we expend on the generator 100 H.P. How much under best conditions can we expect to get at receiving station? 100 H.P. roughly = 75 000 Watts. This enables us to get pressure to which the insulated sphere or capacity C can be charged by this amount of energy.

Let the pressure be P then we have:

$$\frac{1}{2} P^2 \cdot \frac{10000}{9 \times 10^{11}} \cdot 200000 = 75000 \text{ and } P^2 = 67500000 = 6750 \times 10^4.$$

From this $P = 100 \sqrt{6750} = 8200$ Volts roughly. This means to say that we could charge the terminal periodically (200 000 times per second) up to a pressure of 8200 Volts.

Evidently with such small pressure the effect at distance would be qualitatively very small but we can, without using more power increase the pressure many times by resonating action.

For the moment it will be useful to consider what might be done by working with the above pressure of 8200 Volts only. According to law of density referred to before the charge distributes itself over the surface of Earth as illustrated and the density of each zone is inversely as the surface of the zone.

If we use 100 000 vibrations per second the wave length will be about 1.86 miles. Hence $\frac{1}{2}$ wave 0.93 miles. Taking for simplicity density uniformly distributed over the area or zone we may estimate it to be $\frac{2}{3}$ of the maximal.

Let a = area of sphere or terminal of transmitter,

A = area of zone – the last on opposite pole where density greater.

As above assumed the radius r of sphere may be 33 meters or about 100 feet. The radius of polar cap = 0.93 miles 4900 feet approx.

$$\frac{a}{A} = \frac{4r^2}{R^2} = 4 \left(\frac{r}{R} \right)^2 = 4 \left(\frac{100}{4900} \right)^2 = \frac{4}{49^2} = \frac{1}{600} \text{ about.}$$

Under the conditions and with reference to above law, since the quantity of electricity on polar cap is exactly equal to the quantity on sphere C the density of charge on the polar cap will be $\frac{1}{600}$ of that on sphere. From what has been said above, however only $\frac{2}{3}$ of this value or $\frac{1}{900}$ can be taken. If Q the quantity of electricity both on sphere and polar cap, D density on sphere, d density on cap we have: $D = \frac{Q}{a}$ $d = \frac{Q}{A}$ $\frac{D}{d} = \frac{A}{a}$. On the other hand $Q = CP = \frac{10000}{9 \times 10^{11}} \cdot 8200 = \frac{8}{10^5}$. Hence $D = \frac{8}{10^5 \cdot a}$. Here a should be taken in cm square. Now $a = 4\pi \times 3300^2 = 140 \times 10^6$ cm sq. approx.

Therefore $D = \frac{8}{10^5 \times 140 \times 10^6} = \frac{8}{144 \times 10^{12}} = \frac{4}{7 \times 10^{12}}$ and $d = \frac{4}{63 \times 10^{14}}$ as absolute values of D and d respectively.

From the law of density and obvious considerations it follows that the e.m.f. impressed at polar cap will be in the same ratio smaller as the density is smaller or it will be $\frac{8200}{900} = 8$ Volts*

* i.e. 9.1 Volts. - Ed.

As the polar cap gets all the energy of the transmitter less of course the frictional and medium losses which from my tests seem very insignificant, we could theoretically recover all the energy if we could utilize the whole of the successive charges of the cap. We could do so if we would utilize a large

capacity C_1 capable of taking up the whole charge. The capacity C_1 should be such that $C_1 p = CP$. Hence $C_1 = C \frac{P}{p} = 900\bar{C}$. Undoubtedly this capacity could be obtained by vertical wires for instance, distributed over the polar cap at suitable distances. The currents passing into the wires could be converted to suitable tension as usually is in my system. The secondaries could however be connected to advantage only when the currents of same phase. This would probably necessitate the arrangement of the wires in concentric stations at which this condition would obtain. But this difficulty is not a serious one. A wire even then of say 200 feet height might have, with consideration of increase by elevation about 500 centimeter and to make up a capacity of 900×10000 cm as would be required we would want $\frac{900 \times 10000}{500} = 18000$ vertical wires or other kind of terminals. If wires were used about 680 miles would be needed, but

* Negligeable in the manuscript.

they could be thin as the pressure would be small and the air loss consequently negligible*. In addition to this the secondaries would require about as much wire.

The amount of copper seems large – too large in fact for practical purposes but it seems only so because we have assumed but 100 H.P. energy expenditure at transmitter.

Suppose we would install a plant with 10 000 H.P. that is one giving 100 times the energy before assumed. Then, since the e.m.f. at transmitter will be greater in proportion to the square root of the power we would get at transmitting station an e.m.f. of 82000 Volts instead of 8200 as before, and then the polar cap would be charged to 80 instead of 8 Volts.

Here I come to a momentous question: Can the transmitter convey all its energy to the polar cap or can it merely convey the same quantity of electricity?

To be sure the energy in a vibrating system as a wire is conserved but will the Earth behave identically? This is of enormous importance. For if all the energy is conserved then the polar cap will receive all the 10000 H.P. of the transmitting station and of the 18000 wires circuits or terminals each will receive $\frac{10000}{18000}$ H.P. = 416 Watts!!! But – if the transmitter can do no more than to convey the same quantity of electricity which it sets in movement to the polar cap then under the conditions presently considered the energy collected at the polar cap will be small. Namely we could only employ a capacity 900 times as great as that of the transmitter and could only charge it to 80 Volts. To use a greater capacity – even if we could – would seem of no avail since, the quantity of electricity being fixed, we would not be able to charge the capacity to 80 Volts. The maximum of energy we could collect then would be: $\frac{1}{2} \times \frac{900 \times 10000}{9 \times 10^{11}} \cdot 80^2 \times 200000 = \frac{516 \times 10^{13}}{9 \times 10^{11}} = \frac{51600}{9} = 5733$ Watts or we could get only $\frac{5733}{750} = 7.6$ H.P. approx.

Each wire or circuit will then receive only $\frac{5733}{18000} = 0.3$ Watts or a little more an amount of energy extravagantly large for operating automatic devices even such things as clocks but otherwise inadequate.

This seems discouraging but perhaps it can be helped. A consideration here presents itself. If instead of using 100 000 per sec. as assumed we use a frequency much higher, the conditions, all other factors remaining – will be improved. Suppose the same amount of energy is expended on the transmitter with a frequency n times the one before assumed then, since energy $e = \frac{1}{2} CP^2 \cdot 200000$ also $\frac{1}{2} CP_1^2 \cdot 200000 \cdot n$ where P_1 is the pressure in latter case, we have $P_1^2 \cdot n = P^2$ or $P_1 = \frac{P}{\sqrt{n}}$. This means, if a frequency four times the assumed were employed the pressure at transmitter would be $\frac{1}{2}$ of the former that is $\frac{82000}{2} = 41000$ Volts. At the polar cap we would then get, since its surface would be only $\frac{1}{4}$ of the cap on former instance, an e.m.f. of $\frac{80}{2} \times 4 = 160$ Volts, that is twice as much as with the frequency

first assumed and now we could with the same capacity collect 4 times the energy i.e. $7.6 \times 4 = 30.4$ H.P. = 22932 Watts and each wire or circuit would collect 1.2 Watts.

But from the preceding it is clear that, unless radically better conditions can be attained, even with frequencies much higher than the one last assumed, a transmission of energy for industrial uses would not be practicable in this way. Suppose the frequency were, instead of 400 000 per sec – $16 \times 400000 = 6,400,000$ per sec which is manifestly impracticable then even we could get only $16 \times 32 = 512$ H.P. roughly on the whole polar cap and this would hardly pay in power transmission for it would mean a loss of 95% of the power of the transmitter. It should be stated, however, that with such a high frequency the three kinds of losses would be not inconsiderable. Certainly the dielectric loss and radiation would begin to feel.

Returning now to the above important question we may ask: What is it that limits the amount of power transmitted? Surely, it is the small e.m.f. for to all evidence, experimental and theoretical, it ought to be possible to transmit through the earth all the energy of the transmitter to the polar cap as if Earth were a wire, with the exception, of course, of that comparatively small amount unavoidably lost through well known causes. The limitation in the amount of energy collectable on the polar cap is evidently of the same kind as that restricting the energy in a conductor in series with a condenser. The generator supplying the e.m.f. may have any desired amount of energy to deliver but if the e.m.f. is not high enough it is of no use.

This leads to the conclusion that what is necessary is to increase the e.m.f. of the polar cap in any way possible.

So far resonant conditions and advantages of same have been ignored. But by their observance I think the above drawbacks can be largely, if not wholly done away with. First of all it is evident that without expending more power on the transmitter the e.m.f. can be many times increased at the polar cap and conversely the same e.m.f. on the latter can be obtained with an incomparably smaller amount of actual expenditure of power on the transmitter. The same e.m.f. at the transmitter and cap could be certainly obtained with an expenditure of only $\frac{1}{100}$ of the power. This means to say that instead of using 10 000 H.P. we would need only 100 H.P. to get 80 Volts on polar cap. Taking 400 000 per sec on which bases 30 H.P. roughly could be collected we would have an efficiency of 33%! and if it be true this already is worth of very serious consideration.

But from my experiments with these transmitters I should say that much better results are possible. There should be no great difficulty of working with a magnifying factor of say 100 ($\frac{Lp}{R} = 100$). As much as that is easily predictable. The e.m.f. at the transmitter would then be 8,200,000 Volts and of the cap on pole instead of 80 Volts 8000 Volts. This I think would be perhaps too high because with 8000 Volts the frictional air loss would be probably of some consequence, if not serious. The points of structures, wet leaves etc. would at that pressure emit small streamers. This is to be seen later by computing the density. For the present I shall assume that 8000 Volts are obtained at the cap. With this e.m.f. we can now charge a capacity sufficiently large to take up all the energy of the transmitter. This capacity is C_2 and we find it from the equation: $\frac{1}{2} \cdot C_2 \cdot 8000^2 \times 800000 = 10000 \times 750$. $C_2 = \frac{75 \times 10^6}{64 \times 10^6 \times 400000}$ farad = 2640000 cm roughly. This is a capacity only 264 times greater than that of transmitting terminal and could be easily obtained. If the same kind of wires were used for collecting the energy as before each having 500 cm capacity we would want $\frac{2640000}{500} = 5280$ wires only and then figures are much better.

To sum up: it seems that we can get working with a magnifying factor of $\frac{Lp}{R} = 100$ and expending 10000 H.P. at transmitting station, terminal capacity of 10000 cm and voltage maximum of 8,200,000 Volts at the polar cap with frequency of 100 000 per sec. a voltage of 8000 V and can collect all energy

with vertical wires or other terminals 5280 in number each of a capacity of 500 cm and distributed judiciously over the area of polar cap. Each wire would be capable of collecting $\frac{10000}{5280}$ roughly say 2 H.P.

The electrical movement would be, however, much greater since from this it would appear that capacity might be smaller, eventually 2000 wires might do.

The question of density. In the preceding estimated a pressure of 8,200,000 Volts has been assumed at the terminal of transmitter. This may be too high and streamers may impair the efficiency. From experience I know that with the frequency proposed before streamers will break out from a terminal of 1 cm radius of curvature with a pressure of 50000 Volts or thereabouts. In the absence of exact data I shall for the moment take this as the limiting figure. From this we may get an approximate idea of density. Say a spherical terminal of 1 cm radius is charged to a pressure of 50 000 Volts. The quantity

of electricity is $q = 50000 \times \frac{1}{9 \times 10^{11}}$ Coulombs. The surface of sphere is $4\pi \cdot 1 = 12.57 \text{ cm sq.}$ Hence the density of charge: $\frac{50000}{9 \times 10^{11} \times 12.57} = \frac{1}{22626 \times 10^4}$ roughly $\frac{1}{226 \times 10^6}$.

At this density streamers will break out from terminal at any place of smaller radius of curvature.

Now, on the transmitting terminal we have as follows:

The quantity $D = 8200000 \times \frac{10000}{9 \times 10^{11}} = \frac{82}{900} = \frac{8}{100}$ Coulomb.*

The surface of terminal was found before: $a = 140 \times 10^6 \text{ cm sq.}$ Taken exactly as sphere it is about $1328 \times 10^5 \text{ cm sq.}$ but it will be generally larger. Hence it is preferable to take it at $140 \times 10^6 \text{ cm sq.}$ From this,

density $\frac{D}{a} = \frac{8}{14 \times 10^9}$, still far below the critical value.

Energy transmission through Earth with my apparatus and currents of low frequency considered on bases of estimates of June 2

The results were arrived at under tacit assumption of certain ideal conditions which could be only partially realized. But, allowing liberally for all drawbacks the calculations together with results of experiments in Colorado leave no room for doubt that on a large scale energy transmission for industrial purposes is practicable.

I find density in former case was $\frac{8}{14 \times 10^9}$ while the limiting density with 100 per sec was approx. $\frac{1}{226 \times 10^6}$. Making ratio we find $\frac{1}{226 \times 10^6} : \frac{8}{14 \times 10^9} = 8$ which means that we could have in case calculated June 2. employed density 8 times as large. This would mean e.m.f. of 8 200 000 Volts on capacity terminal of transmitter.

From previous considerations it is clear that if all other conditions remain the same and instead of 100 000 per sec 200 per sec currents are used which may still do well with motors we would get with 8,200,000 Volts at transmitter in lieu of 8000 Volts = E on polar cap a smaller e.m.f. $e = \frac{E}{\sqrt{n}}$ where $n = \frac{100000}{200} = 500$ and $\sqrt{n} = 22.4$ approx. from which $e = 360$ Volts only. This would give little energy to be collected by the small individual capacity terminals.

Assuming again 10000 H.P. expended at transmitter the energy at each capacity collected would be in ratio $\left(\frac{360}{8000}\right)^2 \cdot \frac{1}{500} = \left(\frac{9}{200}\right)^2 \cdot \frac{1}{500} = \frac{81}{40000 \times 500} = \frac{1}{500^2} = \frac{1}{25 \times 10^4}$ smaller. Evidently for such low frequency we would want e.m.f. ever so much greater. I think that 400 000 000 Volts would not be impossible with surfaces of large radius of curvature and this for same conditions would give energy in ratio $\left(\frac{400}{8}\right)^2 = 2500$ times greater than preceding value. Or energy collected with low frequency currents

* I.e. ... $\frac{9}{100}$
Coulomb, and
 $\frac{D}{a} = \frac{9}{14 \times 10^9}$
resp. - Ed.

200 cycles p. s. and 400×10^6 Volts would be $2500 \times \frac{1}{25 \times 10^4} = \frac{1}{100}$ of that obtainable with 100 000 per sec and 8,200,000 Volts. As regards transmission of power all these estimates show that high frequency currents are imperative to employ. But if they can be successfully directed or if, without conversion in direct current, motors can be run then a great problem is successfully solved.

June 4, 1901

Test to determine inductance of one of the cables in square frame $8 \times 8'$ in terms of turns of Regulating coil:

One of the cables was connected in series with spark gap and the spiral coil with primary was used to determine period. Across the terminals of primary a minute lamp was connected and the coil shifted to a distance of about 8 feet from square frame.

Resonance was obtained with	{	Turns in Self.Regulator $4\frac{1}{2}$ Capacity: jars in each set 4	}	A comparison of this with result previously recorded under similar conditions of tuning will give inductance. Calculate.
--------------------------------	---	--	---	---

* The inductance of both cables in square frame when connected in series will be four times as large.

Test to illustrate advantage of spiral coil with high pressure terminal in center instead of on the outside. The results give a general idea of the advantage of having the turns near the high pressure terminal or end small to reduce as much as possible effect of capacity. The drawbacks due to internal capacity increase with square of diameter. In telegraphy when a spark gap or metallic powder is used it is for this reason of greatest importance not to have capacity at the terminals of device as great capacity means smaller density. What is desired in working with sensitive microscopic gap or microscopic film of dielectric is great variation in electric density of terminal. The greater the density resulting from the action of transmitter the more sensitive is the receiver. Therein lies the advantage of spiral coil as I use them in such cases.

Test: a) Coil connected as ordinarily, outer end to ground wire

Turns in Regul. coil $5\frac{1}{4}$ Capacity: jars in each set 4	}	fundamental note
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b) Coil connected oppositely, inner wire end to ground wire, outer wire end forming free or high pressure terminal.

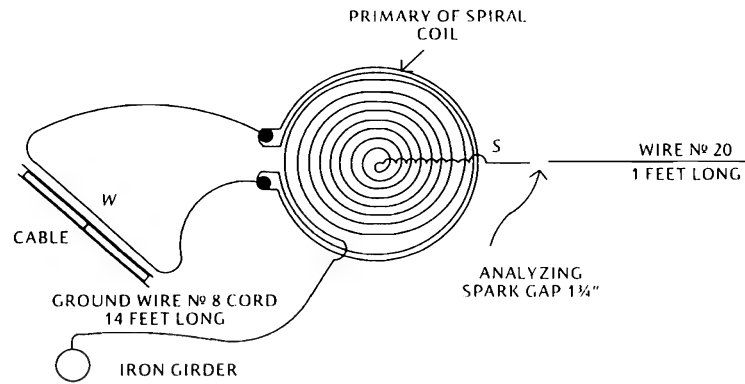
Turns in Regul. coil 14 Capacity: jars in each set 4	}	fundamental note
---	---	------------------

* Here miniature lamp across primary of spiral coil was used as analyzer. The capacity of the primary no doubt is of considerable moment. In an other test for same purpose this will be eliminated

— . —

Observations made in tuning

The arrangement with wire w before described was used first to determine again the period of large spiral coil of № 8 Okonite wire and cord. Spark analysis to determine maxima and minima, connections as illustrated below.



The experiment was first tried to tune by exciting secondary spiral directly with wire w putting latter in series with ground wire and spiral coil but the e.m.f. so obtained was small. The method was then changed to that illustrated in which case the e.m.f. impressed was very high.

Results:

Turns in Self. Regulator $5\frac{1}{8}$
Capacity: jars in each set 6

}

gave fundamental tone
under these conditions

Note: To see to what an extent the length of free terminal wire s might vitiate result the wire was pulled out 1 foot. The vibration remained practically unaltered. This corroborates previous observations that when energy in the system small and pressure at terminal comparatively low the pulling out of the wire produces little change. But when the pressure at terminal very great then the every centimeter of increased capacity counts very much. It should be remembered that the energy stored increases with the square of pressure. The general conclusion arrived at is that while pressure itself does not alter the capacity yet for practical purposes it is as if it did.

The above test left room for a doubt that the primary might have considerably altered the period of the spiral coil. To investigate this, the primary was left open and the ends of wire w were connected to one of the cables in frame square 8 x 8 feet. Thus a primary for the excitation of the spiral coil was obtained, the distance of which could be raised. This gave an idea of influence of primary on period of spiral coil.

Resonance was now obtained with

Turns in Self Regulator $6\frac{3}{8}$
Capacity: jars in each set 6

}

fundamental note

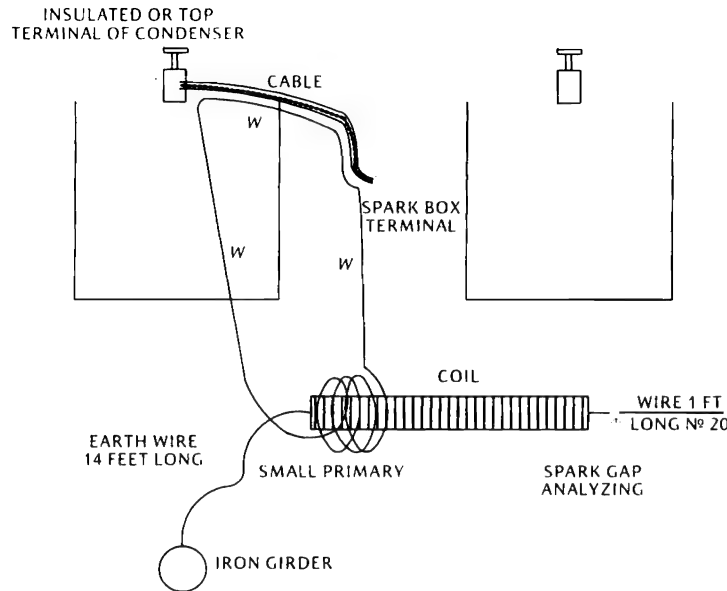
This showed that the primary in first test quickened the vibration appreciably. Obviously the tuning of the coil should be always made with regard to this fact.

To investigate further properties of complex transmitters and receivers and to ascertain best vibrations to be adopted in plant under construction four cores were wound on cylinders of wood of $3\frac{1}{2}$ " diam. and length.

Core A № 23 wire	double cotton covered	1212 turns
" B " 24 "	"	1350 "
" C " 25 "	double but thinner	1489 "
" D " 26 "	insul. as the first two	1389 "

The periods were ascertained in the following manner:

A wire w was fastened with tape to one of the short thick cables connecting the insulated terminal of one of the condensers with the spark gap. The wire was Nr.8 Okonite covered and the portion close to the thick cable was about two feet long. The wire w was left longer and the ends were joined and wound to form three turns, thus giving a primary of sufficient energy to serve the purpose of the tests and one which would have only a negligible influence upon the period of the coil to be experimented with (arrangement is illustrated).



Results:

Turns in Selfind. Regul.		Capacity
Coil A	3 1/8 turns	4 jars (each set series)
" B	4 1/8 "	"
" C	4 3/4 "	"
" D	4 1/4 "	"

Now coils C and D were connected in series. Result was:

Coil C + D	1 5/8 "	4 "
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This was octave evidently.

" C + D	6 1/4 "	4 in one set which corresponds to 8 in each set series.
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To get the fundamental vibration corresponding to the two coils in series one condenser set was short circuited and resonance was obtained with

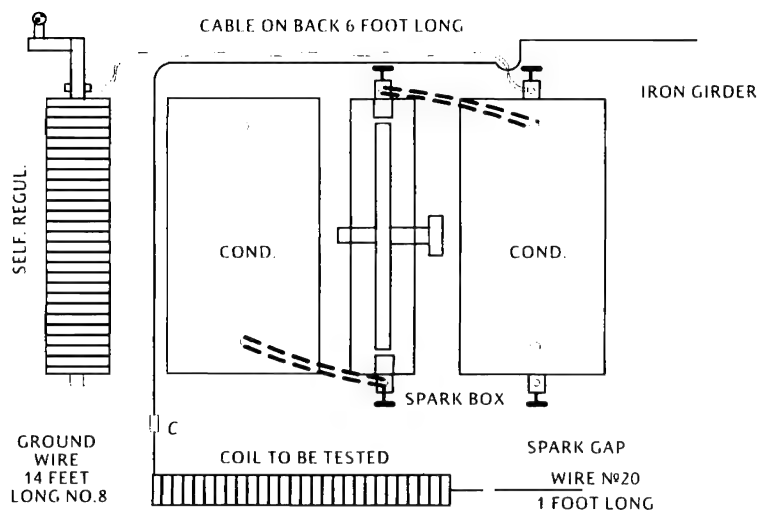
Note. Tuning sharp but must be made much more so

June 5, 1901

Further observations in tuning

In order to eliminate as much as possible influence of source impressing the oscillations upon the freely vibrating circuit the method of inducing a small e.m.f. in ground wire was again resorted to. When tried before the e.m.f. induced was small because the cable from insulated or upper terminal of one of the condensers to terminal of spark box was short. To get higher induced e.m.f. the ground wire was fastened with tape along the longer cable (about 6 feet) on the back of both condenser sets this giving e.m.f. required.

The condensers and positions of the several apparatus are indicated in sketch below viewed from top.



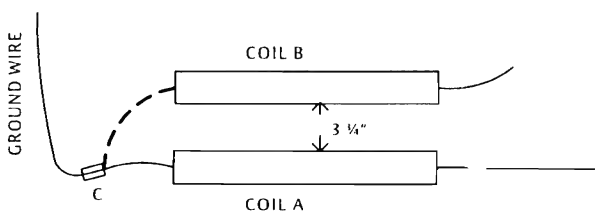
With coil before designated A wound with № 23 wire 1212 turns resonance was obtained with:

3 $\frac{3}{8}$ turns in Self-induction Regulator	} Analyzing spark barely capable of jumping $\frac{3}{4}$ "
4 jars in each condenser set as capacity	

The record of yesterday shows that the vibration was quicker in previous test. The small primary used to induce e.m.f. undoubtedly was the cause of it.

This shows that in exact tuning the present method is preferable.

Now the coil B was placed on two chairs parallel to coil A at a distance of 3 $\frac{3}{4}$ ". Coil B, however, was not connected to ground wire.



The excitation of coil A was exactly the same nevertheless the presence of coil B though not connected in circuit reduced the spark at free end of A very much to $\frac{1}{16}$ ".

The resonating condition was attained with

3 $\frac{3}{4}$ turns in Self. Regul.	} Coil B slowed the vibration in A down as is evident from comparison with preceding result
4 jars in each cond. set capacity	

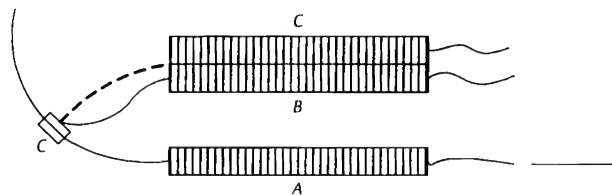
Coil *B* was now connected to ground wire, coil *A* remaining as before. Resonance was presently reached with $2\frac{1}{2}$ turns in Self regulator and 4 jars in each condenser set as before. It was at once observed that the spark at free of coil *A* was stronger, jumping easily over $\frac{3}{8}$ ". It was also decidedly thicker.

This effect was to be expected from previous experiments chiefly in Colorado. When the coil *B* was disconnected again and the end left close to connector *c* the strengthening of spark at free terminal of *A* was still perceptible.

In the experiment which follows an other coil *C* was placed close to coil *B*, coils *A* and *B* being connected to ground wire as in previous test. Resonance of coil *A* was now obtained with

Turns in Self. Regulator $1\frac{7}{8}$
Capacity: jars in each set 4

} The spark at analyzing gap was now weaker



Presently coil *C* was likewise connected to ground wire as indicated by dotted line and vibration of coil *A* was found exactly the same as before, $1\frac{7}{8}$ turns, 4 jars. But spark of coil *A* was stronger and very much so. It jumped over $\frac{7}{16}$ ". It was also perceptibly thicker.

Conclusions: The above seemingly inexplicable phenomena are due to a simple cause and the experiments further confirm theory that excitation of a coil connected to ground as in my system is in proportion to electrical density of ground or ground connection. When coil *B* was placed near coil *A* the former not being connected to exciting ground wire the e.m.f. at free terminal of *A* was reduced both by capacity and to some extent also by induced currents in *B*. The chief cause however was the increased capacity since the coil *B* slowed down vibration in *A*. The induced currents in *B* would have quickened the vibration of *A*, at least this would be reasonable to expect.

When coil *B* was connected to ground wire effect was increased in *A* because of greater density at condenser *C*. The vibration in *A* was quickened probably by inductive action the currents in *B* passing presumably in opposite direction. This I regret to say was overlooked but it will be ascertained on next occasion. When end of *B* was close to connector *c* the strengthening effect was due to similar cause. The same theory explains also the influence of coil *C* above noted.

June 6, 1901

Modified method of determining constants of circuits and ph. quantities

Take a coil wound on long cylinder of length *l*. The inductance will be

$$L = \frac{4\pi N^2 A}{l \times 10^9} \text{ Henry, } A = \text{area.}$$

Determining vibration of coil it will be found

$$T = \frac{2\pi}{10^3} \sqrt{\frac{4\pi N^2 A}{l} \cdot c}.$$

The capacity expressed in μF is here that capacity which would have to be added in circuit with coil if the latter had no capacity whatever. *c* is therefore an ideal quantity which can be determined

from T as in Colorado experiments. Adding to terminals of coil an other capacity C which for the present is assumed as known we would get

$$T_1 = \frac{2\pi}{10^3} \sqrt{\frac{4\pi N^2 A}{l \times 10^9} (C + c)} .$$

Knowing T_1 and T we can then determine C .

Winding an other coil exactly alike to first in all respects except that it is longer we can so adjust it that it has period T_1 without capacity C . Call c_1 the "ideal" capacity of this coil and l_1 the length of the same we have

$$T_1 = \frac{2\pi}{10^3} \sqrt{\frac{4\pi N_1^2 A}{l_1 \cdot 10^9} \cdot c_1} .$$

But as shown in Colorado we shall have $c_1 = \frac{l_1}{l} c$

$$\text{Hence: } T_1 = \frac{2\pi}{10^3} \sqrt{\frac{4\pi N_1^2 A l_1}{l_1 \cdot 10^9 l} \cdot c} = \frac{2\pi}{10^3} \sqrt{\frac{4\pi N^2 A}{l \cdot 10^9} \cdot c} .$$

From this $N_1^2 = N^2 (C + c) \frac{N_1^2}{N^2} = C + c$

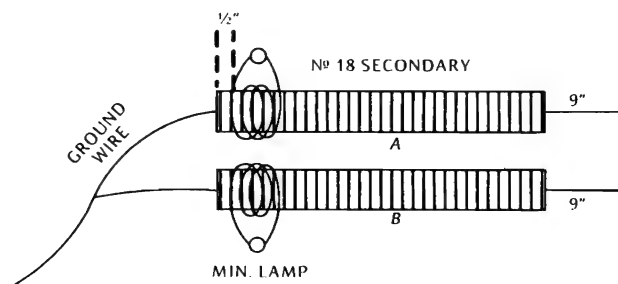
This is a relation which may be very useful.

Note. Two coils of different diameters may be tuned for same period and a relation of their ideal capacities obtained. A known capacity may then be added first to one and next to the other and an other relation obtained containing this capacity as taken. Valuable results by winding same wire successively on cores of different diameters and determining the ideal capacity in each core. Plotting the curve of those will be highly valuable. To follow up.

June 8, 1901

Experiments and observations with tuned coils continued

Coils A , B , C , and D previously described were again used. The "free" end of each was straightened and cut off to 9". Ground wire 14 feet long laid close to cable connection on base of condensers was employed for excitation. Resonance was detected by miniature lamps and for this purpose each coil had a secondary five turns Nr. 18 Okonite wire wound $\frac{1}{2}$ " from grounded end on top of the primary long winding. This was not the position in which the secondary received most of the energy but suited the observation. All secondaries were placed as nearly as possible alike and the excitation was also kept as uniform as practicable in all experiments. The method of using the apparatus did not permit to keep the energy exactly uniform or to determine it exactly in every instance but the estimates were thought sufficiently close for the present purposes.



1. Exp.

Coils *A* and *B* (№ 23 and № 24 wire respectively) both excited as indicated in diagram.

Resonance: 3 turns in Regul. 4 jars in each set of condensers

Observation. Lamp in coil *A* only lights.

2. Exp.

Coil *A* taken off, *B* only remaining. Resonance was obtained with $3\frac{5}{16}$ turns in Regul. 4 jars in each set of condensers.

Observation: Excitation of ground wire had to be much increased in order to light lamp of *B*.

3. Exp.

Coil *A* again connected. Same excitation as last. Lamp on coil *B* again does not light. Lamp on coil *A* very strong.

Observ. In agreement with theory formulated.

4. Exp.

Coils *A* and *C* (25 wire thinner insulation) now used as above.

Resonance: $4\frac{5}{8}$ turns in Regul 4 jars in each set.

Observation: This was resonating condition for coil *C* alone still when coil *B* was connected. Lamp on *C* did not light. All in agreement with theory.

5. Exp.

Coil *A* was disconnected and lamp on *C* lightened then.

Observation: Though lamp lightened it was much weaker than with coil *B*. It shows that coil *C* for same excitation receives less energy than coil *B*.

6. Exp.

Coils *A* and *D* (№ 26 wire) used as described before. Resonating condition corresponding coil *D* (alone) was secured with 4 turns of Regul. coil, 4 jars in each condenser set. The result was the same as in preceding experiments: When the coil *D* was excited alone the lamp lights, when coil *A* connected only lamp on latter lights.

7. Exp.

Observation special: When lamp on coil *A* screwed out of its socket to open the secondary circuit lamp on coil *D* lighted but weaker than when coil *A* was entirely off.

Important: Resonance with both coils connected was obtained with 3 turns in Regulator and 4 jars in each cond. set. This corresponds to vibration of coil *A* alone. It is evident that coil *A* in this case determines and governs preventing the weaker vibration of *D* to assert itself.

8. Exp.

Coils *A* and *D* used again to verify observation made.

Observation now: Both coils connected only lamp of coil *A* lights, but when lamp of coil *D* screwed out the lamp of coil *A* glows less.

9. Exp.

Observation: Coil *C* did not seem to behave as it ought to have, namely its lamp glowed much less than the others. Why? The coil was wound with wire of thinner insulation. Evidently the capacity of the coil is therefore much greater, this means that the vibration can not assert itself properly. To light a

lamp that is to consume a part of vibrational energy of primary the momentum in latter must be great, same as in a mechanical oscillatory system. Great capacity is a drawback. This surely must be correct. It is however in accordance with my previous observations. The resonating condition again established with $4\frac{9}{16}$ turns in Regul. and 4 jars in each set. The vibration was slightly different than before found. This was no doubt due to the fact that an other lamp was used in socket. If the lamp took more current the mutual induction effect is increased and vibration in primary quickened.

10. Exp.

Coils *B* and *C* used as before.

Resonance with $3\frac{7}{8}$ turns Regul. 4 jars in each condenser set.

Observation: Lamp of coil *B* lights, that of *C* not.

11. Exp.

Coils *C* and *D* used gave resonance with $3\frac{13}{16}$ turns and 4 jars in each cond. set.

Observation: Coil *D* lights the lamp not coil *C*. This should not be. So at least it was thought at first. The internal capacity being greater, however, in coil *C* the vibration can not properly take place. Capacity counteracts self-induction hence the momentum must be smaller in *C* than in *D*. This is the best explanation so far.

12. Exp.

The positions of coils *C* and *D* were reversed it being thought possible that the oscillatory apparatus used in the tests affected results.

Observation: lamp of coil *D* again lights and other conditions are found exactly the same as far as can be judged, hence no error in this or preceding experiments which would be traceable to position relative to exciting apparatus.

13. Exp.

Coils *B* and *D*. Both connected gave resonating conditions with: $3\frac{9}{16}$ turns in Regulator and 4 jars in each condenser set.

Observation: Both, lamps of *B* and *D* light. The lamp of coil *D* seems a little stronger. Why? Coil is wound with thicker wire and less turns. Coil *D* has thinner wire and more turns. What one gains by reduction of resistance the other gains in turns. The magnifying factor is in one $\frac{Ip_1}{T}$, in the other $\frac{Lp_2}{R}$.

Here $p_1 = p_2$ and all depends on values of resistance and inductance. We should have if lamps light equally $\frac{1}{2} I I^2 = \frac{1}{2} L i^2$. I current in coil *B*, i current in *D*. From this

$$\text{relation } I : i = \sqrt{\frac{L}{I}},$$

and with reference to above it will be probably true that also

$$\sqrt{\frac{L}{I}} = \sqrt{\frac{R}{r}}; R = \text{resistance of coil } D,$$

$$r = \text{resistance of coil } B.$$

14. Exp.

Coils *B* and *D* connected with free ends in multiple, otherwise conditions same. Resonance was with $3\frac{3}{16}$ turns in Regulator 4 jars in each cond. set.

Observation: The coils were slightly shifted together. This quickened the vibration. In previous experiment it was trifle slower.

15. Exp.

The free ends of coils *B* and *D* were again separated without any change in the position of coils. No change took place in rate of vibration. Resonating condition exactly as before.

Observation: Important to bear in mind that the coils give twice the energy or nearly so. This is in favor of multiple receiver as experimented with in Colorado.

16. Exp.

Coil *B* and *D* were now connected in series with the latter nearer to the ground wire and the small lamps were left in their sockets. Resonating condition was established with 6 jars in one set (that is equivalent to 12 jars in each of the two sets in series) the other set of condensers being short-circuited. $4\frac{1}{4}$ turns in Self. Regul. Lamp on coil *D* lighted but feebly.

Observation: The wire used to close the terminals of the condenser set was used though thick, was strongly heated by currents magnified through condensers in the way known.

17. Exp.

The coils *B* and *D* were again used as before but the lamp in coil *B* which was in preceding experiment screwed a little out of the socket was inserted. Resonance was again with 6 jars (resp. 12) and $4\frac{1}{4}$ turns. The screwing in of lamp on *B* weakened lamp of *D*.

Observation: Tried to get lower and upper tones. Experiments showed that above was fundamental vibration. This confirms former experience.

18. Exp.

In the preceding coil *D* was connected to the ground wire while coil *B* was on the free end. Inasmuch as latter coil was of larger section it was thought that it might affect results appreciably if coil *B* were connected to ground wire or placed in the portion of the circuit in which the current is stronger. Accordingly the position of the two coils was reversed. The resonating condition now took place with 6 jars (resp. 12) and 4 turns in Regulator.

Observation: Lamp on coil *B* now **glowed stronger** than lamp on coil *D* in previous trial. This confirms theory. By right section of conductor nearer to ground should be greater. In the construction of large oscillators this should not be overlooked. In Colorado test type the section was made twice as great near ground.

19. Exp.

Coils *B* *D* and *A* were connected in series in order named beginning from ground wire. The fundamental note was inconvenient to obtain and harmonies were tried. They were too weak to observe with lamps.

Observation: All goes to confirm former experience that it is best to always use quarter wave adjustment and large capacity on end.

20. Exp.

Coil *B* was now used alone and effect of capacity changes on terminal upon amount of energy collected was observed. Tinfoil pieces of various wires and small bodies were successively connected to free terminal. Invariably the addition of capacity diminished the energy furnished to the lamp. Three causes evidently cooperated here:

Observation: 1) The ohmic loss was comparatively great and consequently the capacity magnified the frictional component; 2) There was a loss in the air 3) The inductance was diminished and vibration could not properly assert itself. A part of the electric movement – that near the capacity terminal was of little effect upon the secondary and the lamp.

Observation: relative to preceding: Evidently when determining the resonant rise with a lamp or frictional resistance as in these tests an error is easily made. The capacity prevents a vigorous vibration to take place in the region of the circuit acting upon secondary including the lamp and it may happen that the effect upon the latter is smaller on this account even if the energy going into the circuit through the ground connection is the same or greater. The old experience is again confirmed: a large inductance is always an advantage when conversion through a secondary is resorted to

21. Exp.

To get an idea if air loss is appreciable a polished sphere 3" diam. was connected to free terminal of coil B. Resonance was obtained with $5\frac{1}{4}$ turns in Regulator 4 jars in each set of condensers.

Observation: The sphere diminished the spark length. Evidently then the two other causes were of greater moment and probably the capacity effect the most important element.

22. Exp.

A coil was now employed with a great magnifying factor. It was before referred to having 1100 turns, length about 5 feet. Winding: green Bellwire Nr.18. Resonance took place with $2\frac{1}{4}$ turns and 4 jars in each condenser set

Observation: A small secondary consisting of 4 turns similar to those on other coils was employed in same manner to light miniature lamp. The effect was too strong and secondary was reduced to one turn this still lighting lamp strongly. For same excitation of ground wire energy was eight times as great. Shows how important the magnifying ratio is. When sphere above mentioned was attached to free end vibration was not perceptibly affected and also energy collected was practically the same. Sphere weakens the spark nevertheless. With a sphere 5" diam. the vibration is $3\frac{1}{16}$ turns 4 jars in each set. With coil D connected also to ground wire, without capacity on free terminal the vibration is slightly quickened: $2\frac{1}{8}$ turns 4 jars in each set.

Note. These experiments with one boy to assist took about one hour. Shows convenience of the arrangements now employed. Improvement still to be made in estimating energy.

June 8, 1901

Transmission of energy through Earth. Low frequency considered

Assume frequency of dynamo on plant under process of construction 60 cycles p. sec. and capacity C of terminal insulated 10 000 cm. With full steam pressure on one of boilers I can easily get 150 H.P. This will be only half of actual output. To use the power to the full extent we must charge the terminal to a pressure P given by the equation:

$$\frac{1}{2} P^2 \cdot C \times 2 \times 60 = 150 \times 746 \text{ from which } P^2 = \frac{111900}{60C} = \frac{111900}{60 \times \frac{10000}{9 \times 10^{11}}} = 16785 \times 10^7 \text{ and } P = 10^3$$

$$\sqrt{167850} = 10^3 \times 409.7 = 409700.$$

To take up whole energy we would have to have 409700 Volts initial e.m.f.

It is evident that for direct charge at that frequency this e.m.f. would be too large and hardly practicable. But with my spiral coils it might be so. At any rate let us take $e = 409700$ Volts as initial e.m.f. This e.m.f. would be magnified to e.m.f. $E = \frac{Lp}{R} e$. The magnifying factor I think can easily be 1000 so that we could get 400,000,000 Volts approx. With large curvature terminal I do not think this e.m.f. impossible.

Now estimates of June 2. and previous show that with 82×10^6 and 100 000 per sec. 8000 Volts were obtainable at polar cap. Considering relation $e_1 = e \sqrt{\frac{n}{n_1}}$ we would get with 82,000,000 Volts and 60 cycles per sec. on polar cap $e_1 = 8000 \sqrt{\frac{60}{100000}} = 80 \sqrt{6} = 196$ Volts. With 400×10^6 we may say, as rough approximation 1000 Volts. Under these conditions we would get with a capacity of say 100 000 cm which can be easily obtained with wires: $\frac{1}{2} \cdot 1000^2 \cdot \frac{100000}{9 \times 10^{11}} \cdot 2\pi \times 60 = 2$ Watts about. This is enough to demonstrate practicability of power transmission. As for telegraphy we only want capacity of 100 cm. We would get to work instruments $\frac{2}{1000}$ Watts. Current at transmitter 10000 cm, terminal capacity $I = eC\omega = 1700$ Amp roughly. This I think is realizable.

June 9, 1901

Vibrations determined, using new ground wire 14 feet long, excited as before.

Large spiral coil; miniature lamp for detecting max. effect. Lamp in secondary.

a) Resonance with 6 jars in each set $5\frac{7}{8}$ turns Coil normally excited

b) " " 6 " " $12\frac{1}{2}$ " " oppositely "

Note: The two tests show detrimental effect of capacity. The magnifying ratio is much smaller in latter test.

Large spiral coil with open secondary spark analysis:

a) 6 jars in each set $6\frac{3}{4}$ turns in Regul. spark strong

b) 6 " " 13 " (about) spark does not jump.

Note: Large capacity is greater drawback still when a device requiring high e.m.f. is used in telegraphy as sensitive receiver than when device frictional as bolometer etc.

Inductance coil used in connection with spiral coil:

Resonance with $3\frac{1}{2}$ turns 4 jars in each set of condensers.

Observ.: Spark on analyzing gap remarkably small: $\frac{1}{8}$ ". Illustrates again advantage of small diameter on high tension resonating coils. Arrangements as in Colorado are best to employ.

With 6 jars in each set $2\frac{1}{16} - 2\frac{1}{8}$ turns a harmonic obtained.

Observ.: The spark is stronger ($\frac{3}{16} - \frac{1}{4}$) but exciting current is also greater. It is not sure that note fundamental.

Same coil with lamp analysis; lamp placed on loop on lower end of coil consisting of one turn.

Resonance:

4 jars in each set $3\frac{3}{8}$ turns Lamp bright

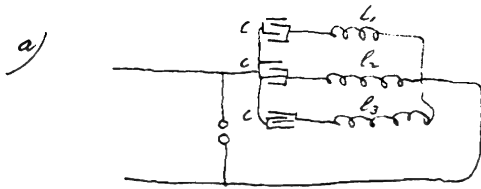
With 6 jars $1\frac{13}{16}$ turns Lamp much brighter

Observ. The latter tests again do not settle doubt as to whether test note fundamental. This is not first time that difficulty noted has presented itself. Accidentally the conditions are such. Shows necessity of keeping always account of the amount of energy used in exciting circuit.

June 13. 1901.

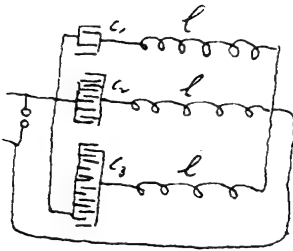


Some of the arrangements experimented with before to be reconsidered with view of getting at best transmitter of complex vibrations.



In this case equal capacities C, C, C and different inductances L, L, L are employed which give a complex vibration chiefly of three distinct vibrations.

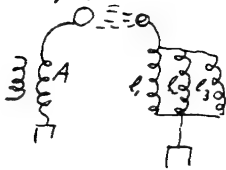
b) Similar arrangement with different capacities C, C, C and same inductances is practicable but hardly is as advantageous as the first. Arrangement under c) below allows more latitude in adjustment. It is important in all three cases to get same energy. Not necessarily the same actual energy but as in telegraphy the same energy qualitatively.



c) Arrangement with different capacities and different inductances.

In all these three cases best results by far are obtainable with resonating secondaries.

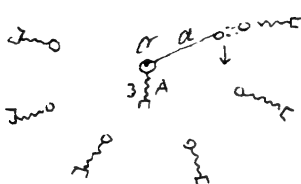
d) following disposition is excellent to use with small apparatus.



A resonating secondary discharging the accumulated energy into complex transmitter. The three circuits can be together. I find it practicable to work seven in this manner.

Working principle of complex receivers the number is probably as large as will be required in telegraphy across sea.

e) Better however is to separate circuits L, L, L - i.e. C and discharge successively and in rapid repetition as illustrated below.



The circuit AC into the transmitters grounded on same or different points. It is easy when spark discharge is used to rotate the device & establishing the successive contacts at great speed, also with mercury break great speed practicable. The energy in circuit AC should be in excess and that is easy to secure.

Results with tuned coils. Data for reference.

One of the new six coils made of steel loop and fibre 4" wide was employed. The loop of this flat steel was joined with fibre so as to be solid yet not closed. To the terminals of loop was connected a condenser approximately $\frac{1}{2} \mu\text{F}$ and a miniature lamp for analyzing maximum. Resonance was obtained with:

14¼ turns in Regulator $\frac{1}{2} \mu\text{F}$ Capacity.

Diameter of loop with be given later. This can be used for calculating frequency.

Large coil with white string tested by inducing currents with cable in square frame. Three tests were made:

Reson. with a)	5¾ turns	2 jars in each set	} This will do for establishing relation and equivalency of turns and jars etc.
	3 "	3 " "	
	0 "	4 " "	

Of the six coils three were wound with wire № 26 triple covered cotton 98 turns. Using miniature lamp in steel loop to analyze vibration resonance was found with

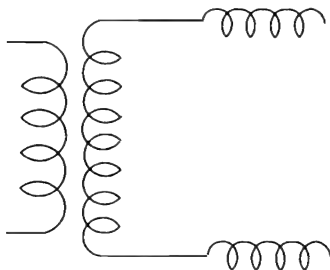
5¼ turns Regul. 4 jars in each cond. set.

In this test the large cable in square frame was included in the circuit.

Now the large cable was taken out and connection made in the normal way. Resonance took place with

8¼ turns Regul. 4 jars in each cond. set.

This coil was marked 1 and the others respectively 2 and 3. The two last named gave exactly same result: Resonance was with 8¼ turns and 4 jars as before. This shows that coils may be manufactured all right.



In the last test the three coils were connected in series. Resonance was obtained with 16¼ turns 4 jars. With the note of each no effect. With 16¼ turns 4 jars miniature lamp not much weaker than with single coil. To remember

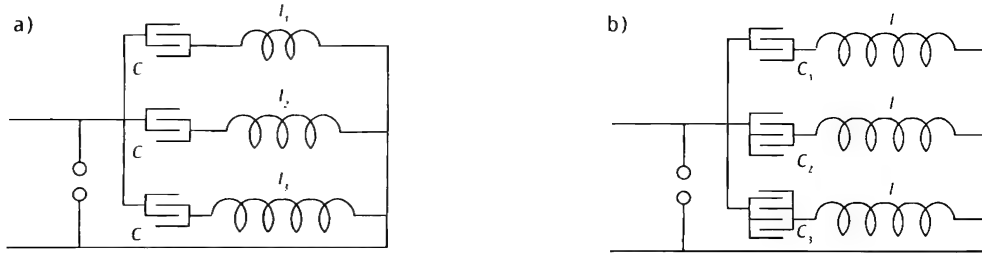
June 13, 1901

Some of the arrangements experimented with before to be reconsidered with view of getting at best transmitter of complex vibrations.

a) In this case equal capacities $c_1 c_2 c_3$ and different inductances $l_1 l_2 l_3$ are employed which give a complex wave chiefly of three distinct vibrations.

b) Similar arrangement with different capacities $c_1 c_2 c_3$ and same inductances is practicable but hardly as advantageous as the first. Arrangement under c) below named allows more latitude in adjust-

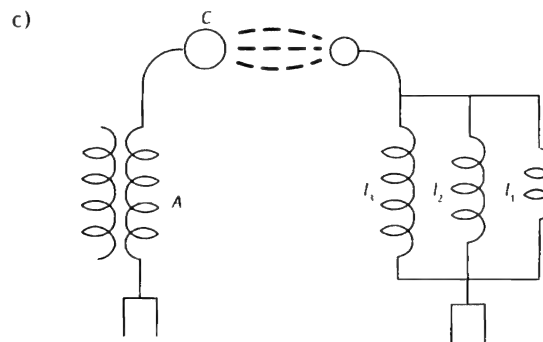
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c) Arrangement with different capacities and different inductances.

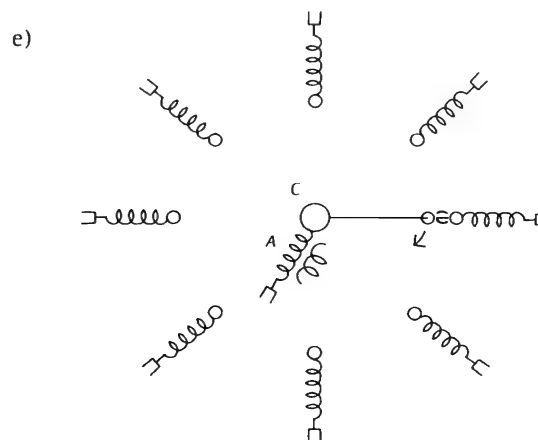
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A resonating secondary discharging the accumulated energy into complex transmitter. The three circuits can be together. I find it practicable to work seven in this manner. Using principles of complex receivers the number is probably as large as will be required in telegraphy across sea.

e) Better however is to separate circuits I_1 , I_2 , I_3 etc. and discharge successively and in rapid repetition as illustrated below same in different points. It is easy when spark discharge is used to rotate the device a establishing the successive contacts at great speed. Also with mercury break great speed practicable. The energy in circuit AC should be in excess and that is easy to secure.



June 14, 1901

521

Small circle of thick aluminium wire and miniature lamp used in many experiments. Inductance of same

Diameter of circle $22.25'' = 56.5$ cm

Radius $A = 28.25$ cm

Diameter of aluminium wire $\frac{1}{4}'' = 0.635$ cm

radius $a = 0.317$ cm

$$8A = 28.25 \times 8 = 226$$

$$4A = \frac{226}{2} = 113$$

$$\frac{8A}{a} = 712 = 8 \times 89$$

$$\log_e \frac{8A}{a} = 2.08 + 4.49 = 6.57$$

$$L = \pi [113 (6.57 - 2) + 0.635(6.57 - 1.25)] =$$

$$\pi (516.4 + 3.4) = 3.1416 \times 520 = 1634 \text{ cm approx.}$$

This circle connected to condenser small $\frac{1}{2} \mu\text{F}$ probably gave resonance with:

5 jars in each set 12 turns in Regulator.

For further reference.

— . —

Two coils as nearly alike as practicable were made for the purpose of ascertaining vibrations of large laboratory apparatus by means of $\frac{1}{2} \mu\text{F}$ standard condenser.

The core of wood was 3.1 cm diam. It was wound with special wire № 14 ($\frac{64}{1000}$ diam.) covered with very thick insulation rubber and bredding. Diameter of wire over insulation $\frac{4}{10}'' = 1$ cm. This gives real diameter (inside) of core $3.1 + 1 = 4.1$ cm. From this:

$$\text{Area } 4.1^2 \times 0.7854 = 13.2 \text{ sq. cm.}$$

Turns coil a 42.75

" " b 42.50

Length of coil a 46 cm

" " b 46 "

Average inductance:

$$L = \frac{42.5^2 \times 12.57 \times 13.2}{46} =$$

$$L = 6520 \text{ cm.}$$

Both coils in series:

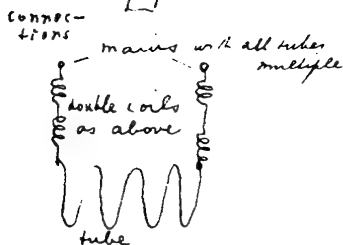
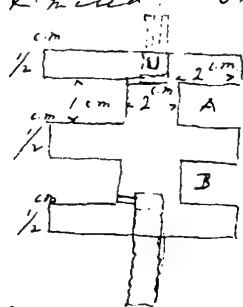
$$L_2 = 13040 \text{ cm.}$$

For future reference



June 24. 1901.

Approximate estimate of coils to be used in connection with vacuum tubes in shop. Two coils are to be placed in series with each tube to effect regulation as well as improve working. The impedance of the coils should be high as compared with resistance of tube so that variation in latter will not much affect the current through coils. At the same time the actual loss of energy in the inductance should be small. The coils should be properly tuned and it is proposed to use small condensers each of a few C.M. of surface. Coils should be of a form to give highest inductance. The theoretically best dimensions can not be taken but approximated. Sketch below shows frame or bobbin of hard rubber with transplugs for connections. The sizes given are convenient because of commercial dimensions of rubber rods.



By Maxwell for each part $A \approx B$ we get

$$L = 8 \pi n^2 \text{ approx. mks.}$$

Total Self-induction in circuit with

$$\text{tube will be } L = 4 \times 8 \pi n^2 = 100 n^2 \text{ C.M. approx.}$$

Suppose we use wire No. 26. We shall put about 500 turns in each part $A \approx B$.

$$\text{This will give } L = 100 \times 25 \times 10^4 = 25 \times 10^6. \text{ Total will give } L = 10^8 \text{ mks. or } L = \frac{1}{10} \text{ Henry.}$$

I think with this inductance spacing of sockets on tubes will probably suffice. To be ascertained by experiment.

June 15, 1901

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It has been assumed in previous experiments that a circuit grounded on one end and free on the other vibrate just half as fast as when free on both ends. To verify this one of the new coils with breaded paraffined wire was taken and suspended in the vertical square frame. It was first excited with both ends insulated and resonance was obtained with $8\frac{1}{4}$ turns in Regul. 1 jar in each set. Being now grounded on one end the resonating condition should have been

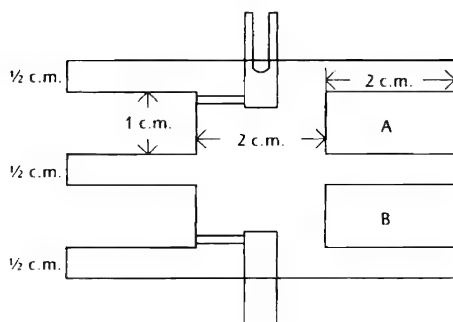
Coil { turns:
diam.: established with 4 jars and $8\frac{1}{4}$
length:

But it was found that it took place with 4 jars and $4\frac{1}{2}$ turns in Regulator. The vibration was quicker than expected. The explanation is easily found. When the circuit is open the internal capacity – the effective – is of greater moment. Various jars were placed in circuit in succession to avoid error due to different capacity of individual jars and resonance was obtained with $8\frac{1}{2}$, $7\frac{1}{4}$, $4\frac{1}{2}$, $8\frac{1}{2}$ etc. But when coil again grounded on one end resonance was with 4 jars and $3\frac{1}{4}$ turns in Regulator selfind. It follows from this that with open circuit grounded we get always a little smaller wavelength than twice that obtained with circuit not grounded. I think this demonstrates that it is always better to use circuits grounded on one side. They will give stronger effects.

June 24, 1901

Approximate estimate of coils to be used in connection with vacuum tubes in shop. Two coils are to be placed in series with each tube to effect regulation as well as improve working. The impedance of the coils should be high as compared with resistance of tube so that variation in latter will not much affect the current through coils. At the same time the actual loss of energy in the inductance should be small. The coils should be properly tuned and it is proposed to use small condensers each of a few cm sq. surface.

Coils should be of a form to give highest inductance. The theoretically best dimensions can not be taken but approximated. Sketch below shows frame or bobbin of hard rubber with brass plugs for connections. The sizes given are convenient because of commercial dimensions of rubber rods.





June 27, 1901.

Experiments on the Tuned Coils

The coils in all respects alike were wound on wooden cylinders of exactly the same dimensions as those used for coils A B C D before described. The two coils were wound with the green wire used before. There were 547 turns in each coil. In testing the excitation by means of the ground wire in tuning was avoided by, the wire being tied by tape to the front cable leading from top terminal of condenser on left to spark gap. The part of ground wire exposed to strong induction from cable was about two feet.

Observations:

Resonance with one of the coils connected as described was obtained with:

$1\frac{15}{16}$ turns in Reg. 1/4 on each side

Analyzing Spark just jumped $\frac{5}{8}$ "

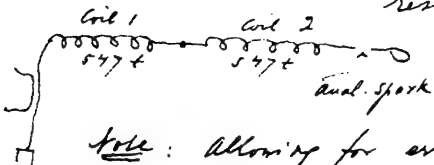
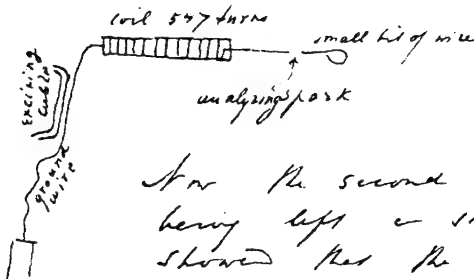
Now the second coil was put in line with the first, there being left a small space for a spark between. Test showed that the placing of the second coil did not perceptibly affect the vibration of the first. Resonance was exactly as above.

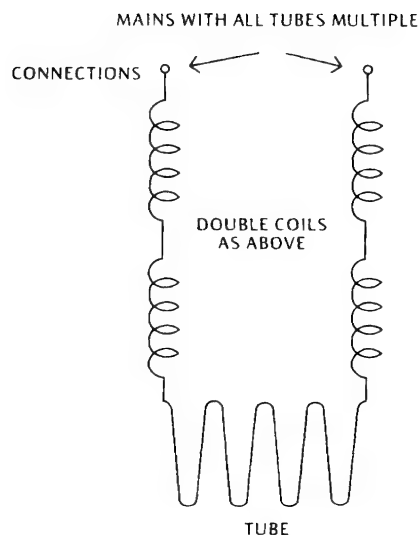
The two coils were now connected in series. In first experiment resonance was obtained with:

$7\frac{5}{8}$ turns and 1/4 on each side of condensers

The analyzing spark was just a little over $\frac{1}{8}$ "

Note: Allowing for error the e.m.f. with two coils in series was with same intensity of excitation just $\frac{1}{4}$ of e.m.f. obtained with the analyzing spark gap with one single coil. Theoretically this should be so, for we had just half the frequency as the wavelength was twice, resistance and self-induction double. Evidently the magnifying factor $\frac{p}{R}$ was with two coils in series just one half, since p was one





By Maxwell for each part A or B we get $l = 8\pi n^2$ approximately. Total self-induction in circuit with tube will be $L = 4 \times 8\pi n^2 = 100 n^2$ cm approx.

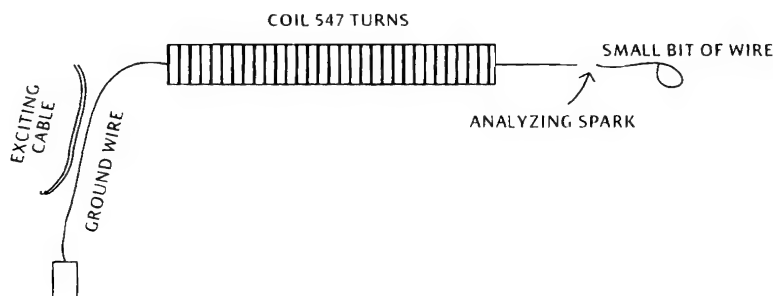
Suppose we use wire No 26. We shall get about 500 turns in each part A or B . This will give $l = 100 \times 25 \times 10^4 = 25 \times 10^6$. Total will give $L = 10^8$ cm or $L = \frac{1}{10}$ Henry.

I think with this inductance capacity of sockets on tubes will probably suffice. To be ascertained by experiment.

June 27, 1901

Experiments with tuned coils.

Two coils in all respects alike were wound on wooden cylinders of exactly the same dimensions as those used for coils $A B C D$ before described. The two coils were wound with Nr... green covered bell wire. There were 547 turns in each coil. In testing, the excitation by means of the ground wire 14' long was resorted to, the wire being tied by tape to the front cable leading from the terminal of condenser set on left to spark gap. The part of ground wire exposed to strong induction from cable was about two feet.



Observations:

Resonance with one of the coils connected as described was obtained with:

$1\frac{15}{16}$ turns in Regul. 1 jar on each side

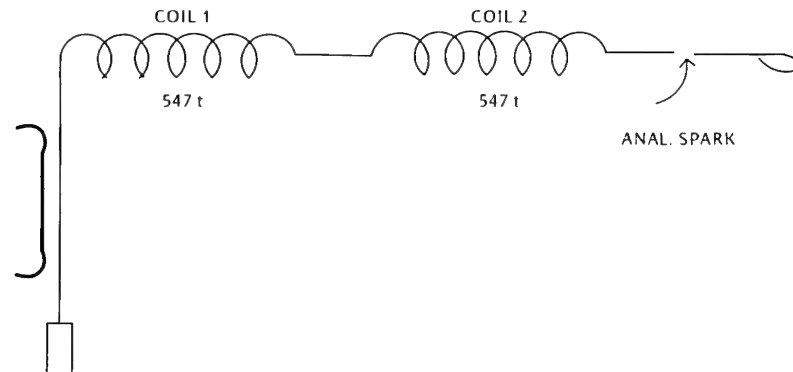
Analyzing spark just jumped $\frac{5}{8}$ "

Now the second coil was put in line with the first, there being left a small space for a spark between. Test showed that the placing of the second coil did not perceptibly affect the vibration of the first. Resonance was exactly as above.

The two coils were now connected in series. In first experiment resonance was obtained with:

$7\frac{5}{8}$ turns and 1 jar in each set of condensers.

The analyzing spark was just a little over $\frac{1}{8}$ "



Note. Allowing for error the e.m.f. with two coils in series was with same intensity of excitation just $\frac{1}{4}$ of e.m.f. obtained at the analyzing spark gap with one single coil. Theoretically this should be so, for we had just half the frequency as the wavelength was twice, resistance and self-induction double.

Evidently the magnifying power $\frac{pL}{R}$ was with two coils in series just one half, since p was one half of what it had been with one coil alone. This would give one half of e.m.f. obtained in first experiment. But it should be remembered that while the condensers were excited to same degree as in experiment with one coil, the exciting current through cable inducing in ground wire was smaller. We had with same capacity in primary four times the inductance in experiments with two coils connected in series. Now four times the inductance would have meant one fourth of the current through exciting cable, had the frequency been the same as in first experiment. But the frequency was only one half, the current through cable therefore one half and not one quarter of primary current obtained in first experiment.

To sum up: in second experiment we had $\frac{1}{2}$ of exciting current and $\frac{1}{2}$ of the frequency hence just $\frac{1}{4}$ of the e.m.f. on analyzing spark gap because $\frac{\text{inductance}}{\text{resistance}}$ remained the same in both cases. The above is important to bear in mind.

Experiments were now continued with two coils in series and capacity was gradually increased in primary. The results were as follows:

2 jars on each side	$4\frac{13}{16}$ turns	Spark analyzing $\frac{3}{8}$ "
3 " "	$2\frac{7}{8}$ "	" $\frac{1}{2}$ "
4 " "	$1\frac{13}{16}$ "	" $\frac{5}{8}$ "

Note. We see that the spark at analyzing gap increases as the exciting current in primary gets stronger until with just four times the capacity and inductance just the same as in experiment with one coil we get same e.m.f. on gap.

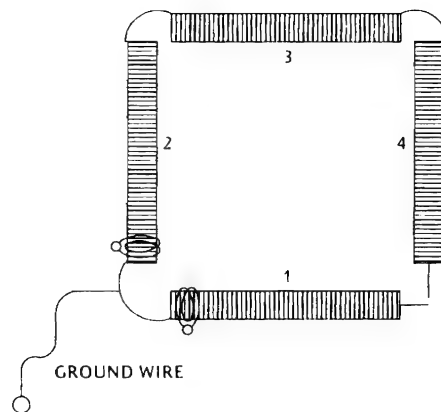
Experiment was now tried with the two coils connected in multiple arc. The resonating condition was obtained with $\frac{1}{2}$ jar in each condenser set and 4 turns in Regulator. The inductance in the double coil was evidently reduced to one half.

Note. There is perhaps an error in above reasoning. To be resumed.

July 6, 1901

Experiment with four coils exactly alike, 547 turns each. Dimensions to be given later in detail. The object of the experiments was to see in how far the effect in a measuring apparatus connected to the ground may be increased by mutual action of circuits.

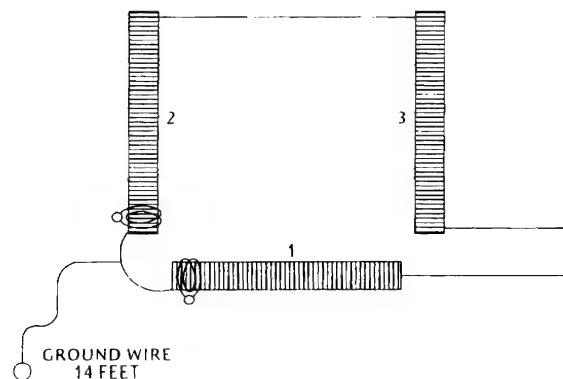
I. Exp.



The coils were connected as indicated, two systems being formed which were in multiple to the ground wire, the latter being energized by back cable on condensers as described on a previous occasion, System 1 had one quarter of wavelength, system 2, 3, 4 three quarter.

No matter how tried the one with one quarter wavelength lighted the lamp (miniature, taking little energy) better. This, however, may not be absolute proof that the system was better for relatively fewer turns were utilized in system 2, 3, 4. Perhaps by putting a secondary on middle portion of coil 3 the additional energy might have been obtained. Minute sparks at e could never be overcome. Quite probably they were due to harmonics which in the system 2, 3, 4, were necessarily different from those in system 1.

II. Exp.



Connected as here indicated; when system 2, 3 was added the lamp of 1 lighted the same, there being no change whatsoever. When end wires of 1 were brought together so as to have capacity increased again no change in intensity of lamp of coil 1.

When wires at 1 connected together again no effect. Here the system 2, 3 had one half and system 1 one quarter wave. Capacity influence was beautifully shown with these coils: when the hand was brought near coil 1 - the vibration of primary being first slowed down; lamp of coil 1 first brightened, then went out by further approach.

Note: Today when jars adjusted, primary inductance was the same. This to be further investigated.

July 7, 1901

Circuit for controlling model boat in laboratory by induction from the large cable was constituted as follows:

In the inside of the boat three turns of rubber covered wire were laid which were joined in series with a small condenser (one of the twenty four used in experiments in Colorado) and a coil of 20 turns rubber-wire same wire (No 16) wound on a new wooden spool 3" diameter. The apparatus for producing the oscillations in the cable was adjusted until resonance was obtained with

8¼ turns Regul. Inductance

2 jars in each set of condensers.

Approximate estimate of vibration period:

The total inductance in the primary exciting circuit including the cable was about 100000 cm or $\frac{1}{10^4}$ H. The capacity was that of one jar about 0.019 μ F.

$$\text{Hence } T = \frac{2\pi}{10^3} \sqrt{0.019 \cdot \frac{1}{10^4}} = \frac{2\pi}{10^5} \cdot 0.138 = \frac{0.866}{10^5} = \frac{866}{10^8}.$$

From this $n = \frac{10^8}{866} = 115000$ per second.

In associating with the 20 turns on new spool a secondary, the period will quicken somewhat so that we may take about 120000 per sec. For this frequency a secondary should be wound without capacity on the terminals. Using as detector a simple spark gap capacity should be as small as practicable.

The wavelength λ will be roughly $\frac{186000}{120000} = \frac{186}{120}$ miles and the length of the secondary theoretically $\frac{\lambda}{2} = \frac{186}{240} = 0.7833$ miles = approx. 4000 feet. As each turn of secondary will be about 9 inches we want about 5000 turns rather less.

Particulars about small oscillator with mercury stream break used for running vacuum tubes in laboratory

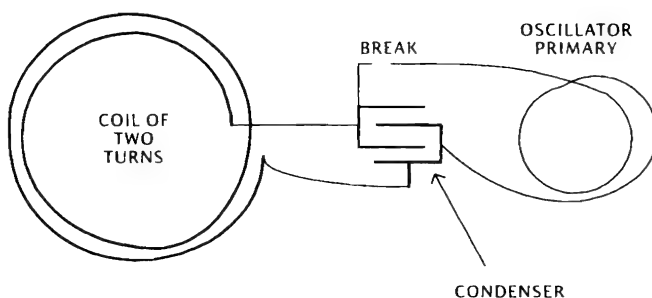
Secondary coil rewound: } Each part $40 + 345 = 385$ turns.
 each side of coil 40 turns in first 2 layers
 + 15 layers ≈ 23 turns
 Condenser about $3.5 \mu\text{F}$
 Total turns in secondary 775

Primary of copper sheet $\frac{1}{100}$ " thick, $6\frac{1}{4}$ " wide, mean diam. of coil of $7\frac{1}{4}$ " nearly.

Approximate estimate of vibration period:

Resonance method was employed as follows: Large cable in room has a loop. This loop was wrapped together with a coil of two turns of wire and the currents induced by the cable loop in the coil were used to ascertain vibration of the system of small oscillator. In the test the mercury control was replaced by a wire connection of small resistance.

The sketch illustrates arrangement.



The frequency of the currents in coil with two turns excited from cable loop was raised until resonance was obtained.

For detection a miniature lamp employed which was included in a secondary winding of few turns placed in inductive relation to primary of oscillator. Resonance with the primary exciting system was obtained with constants in the primary exciting system as follows:

Inductance:

a) all turns of regulating coil and connections	say	90000 cm
b) two turns of stout cable on square frame series	"	32000 "
c) large cable around room	"	50000 "
d) Inductance coil 18 turns Okonite № 10	approxim.	326000 "
	total	498 000 cm

Capacity: 5 jars approx. $5 \times 0.0195 = 0.0975 \mu\text{F}$.

$$\text{From this } T = \frac{2\pi}{10^3} \sqrt{0.0975 \cdot \frac{498}{10^6}} \text{ roughly } T = \frac{44}{10^6} \text{ } n = 23000 \text{ per sec.}$$

Estimated in an other way: Inductance of primary coil of small oscillator was determined and for 8 turns found 17600 cm. Presently, however, the primary had six turns. Considering connections the inductance of all will not be far from 12000 cm. With condenser $3.5 \mu\text{F}$ this would give for period T value

$$= \frac{2\pi}{10^3} \sqrt{3.5 \cdot \frac{12}{10^6}} = \frac{2\pi}{10^6} \cdot 6.48 = \frac{40.7}{10^6} \text{ and } n = 24500 \text{ per sec.}$$

The former estimate is more reliable.

July 8, 1901.



Particulars about Small oscillator with mercury stream break used for running vacuum tubes in laboratory.

Secondary coil wound: Each side of coil 40 turns in first 2 layers }
+ 10 layers = 23 turns }

Each part $40 + 345 = 385$ turns

Total turns in secondary 770

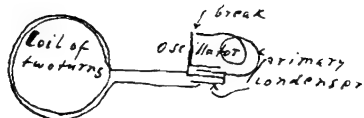
Condenser about 3.5 M.F.

Primary of copper sheet $\frac{1}{100}$ " thick $6\frac{1}{4}$ " wide mean diam. of coil $7\frac{1}{4}$ " nearly.

Approximate estimate of vibration period:

Resonance method was employed as follows: Large cable in room has a loop. This loop was wrapped together with a coil of two turns of wire and the currents induced by the cable loop in the coil were used to exert vibration of the system of small oscillator. In the best the mercury contact was replaced by a wire connection of small resistance. The

sketch illustrates arrangement.



The frequency of the currents in coil with two turns excited from cable loop was raised until resonance was obtained. For detection

a vacuum pump employed which was included in a secondary winding of few turns placed in inductive relation to primary of oscillator. Resonance with the primary circuit system was obtained with condenser in the primary circuit system as below:

Inductance: a) all turns of separate coil and connections say 90,000 c.m.
b) two turns of steel cable in square frame series " 32,000 "
c) large cable around room say " 50,000 "
d) Inductance coil 18 turns thoride #10 approx. 32,000 "
Total 494,000 c.m.

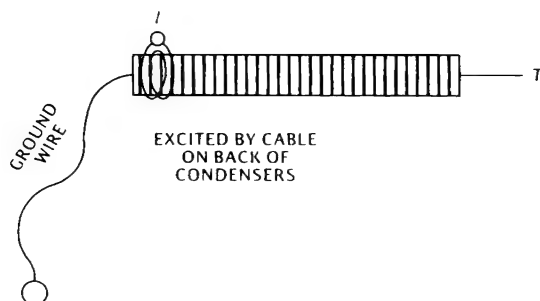
Capacity 5 jars approx $5 \times 0.0195 = 0.0975$ M.F.

From this $T = \frac{2\pi}{10^3} \sqrt{0.0975 \cdot \frac{498}{10^6}}$ roughly $T = \frac{44}{10^6}$ and $n = 23,000$ per Sec.

Estimated in another way: Inductance of primary coil of small oscillator was determined and for 8 turns found 17,600 c.m. Presumably however the primary had six turns. Considering connections the inductance of all will not be far from 12,000 c.m. with condenser 3.5 M.F. this would give period

T value = $\frac{2\pi}{10^3} \sqrt{3.5 \cdot \frac{12}{10^6}} = \frac{25}{10^6} \cdot 6.48 = \frac{40.7}{10^6}$ and $n = 24,500$ per Sec.

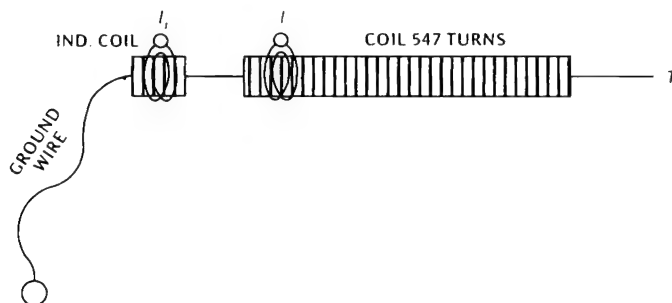
The former estimate is more reliable.



One of the four coils, 547 turns each, before described was used in many ways, capacity being attached to free terminal T . No matter what capacity was given to T it was found that when a fixed amount of energy was supplied through the ground wire to the coil the best result was obtained with no capacity on terminal T .

The lamp I before mentioned lighted always stronger when the capacity of the system was smaller. This was found already in previous experiments. This would agree perfectly with theory. When more capacity is added to the excited system it becomes slacker and hence a small frictional resistance can not be so easily overcome as when the system has a great amount of self-induction and little capacity that is when it is resembling a very stiff spring loaded with a big weight. The conclusion of importance is that one can not follow a better rule in the construction of receiving circuit than the one before given – that is to construct the circuits so that they will have the greatest amount of self-induction and the least capacity.

In order to perform experiments as the above under better conditions a small inductance coil was inserted in the ground wire. The coil had six turns of secondary. The primary was formed by a wire same as the ground wire wound in two layers and having about 14 turns.



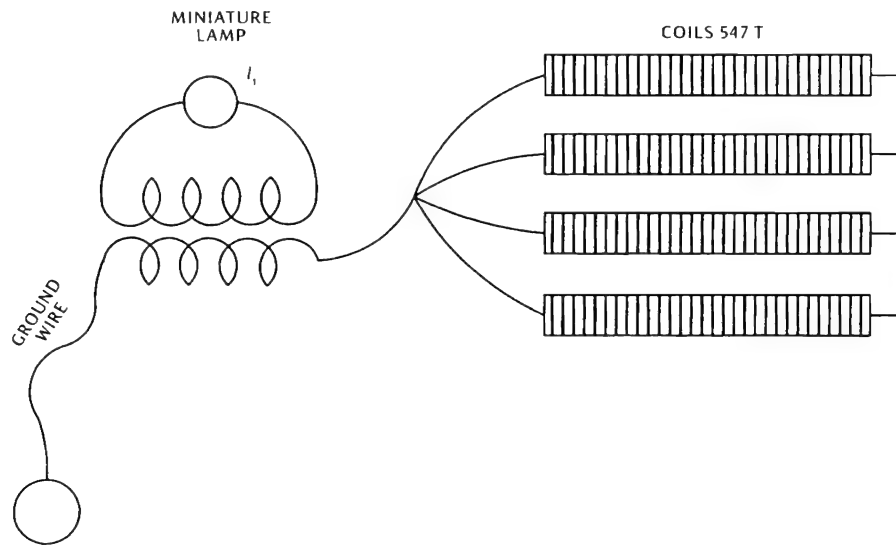
The chief idea in employing the small induction coil in the ground wire was to keep the same analyzer in all experiments; furthermore to dispense with the lamp I on the coils tested.

When the arrangement as indicated in sketch was tried, it was observed that when the lamp I on coil (547 turns) lighted, the lamp I_1 included in the secondary of the induction coil did not light. When lamp I was turned off, I_1 lighted, but weaker than I . The difference in the intensity of both the lamps did not mean anything in itself, for it was clear that it was merely a question of turns which lamp lighted stronger. The important observation was that I_1 did not light at all when I lighted strongly. Evidently when the latter lamp was inserted the current through the ground wire was weaker than when the lamp was off. The best explanation of the phenomenon seems to be the following: When lamp I is not inserted in the secondary of coil with 547 turns there is a strong movement in the latter owing to the absence of frictional resistance, hence a greater rise of current and lamp I_1 lights. But when lamp I is inserted the frictional load pulls the vibration down and the current is reduced so that lamp I_1 can not light. It should be remembered however that the frictional load is greater with both lamps in and therefore the resonating rise smaller when they are both used than when inserted singly. The phenomenon may how-

ever to a small extent be due to the well known action of two unequal inductances or unequally loaded transformers in series.

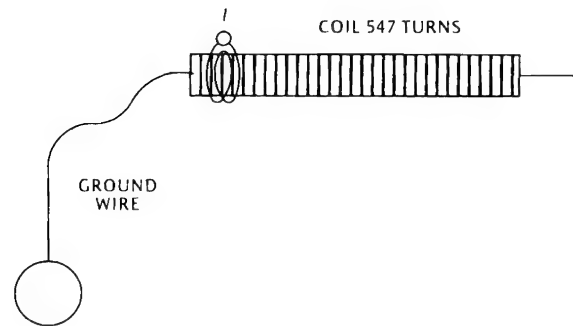
The small induction coil above described inserted in the ground wire was now used to ascertain how the energy taken up changes with the number of coils. The four coils each 547 turns were used in the experiments, the small secondaries with their lamps as I being done away with. It was found that by the addition of coils the current passing through the ground wire was increased. Numerous experiments showed:

- a) The energy taken up through the ground wire increases exactly in proportion to the number of coils. Four coils take up four times as much as a single coil.
- b) The vibrations quicken as more coils are added, that is when four coils are connected the system vibrates somewhat quicker than when a single coil is used.



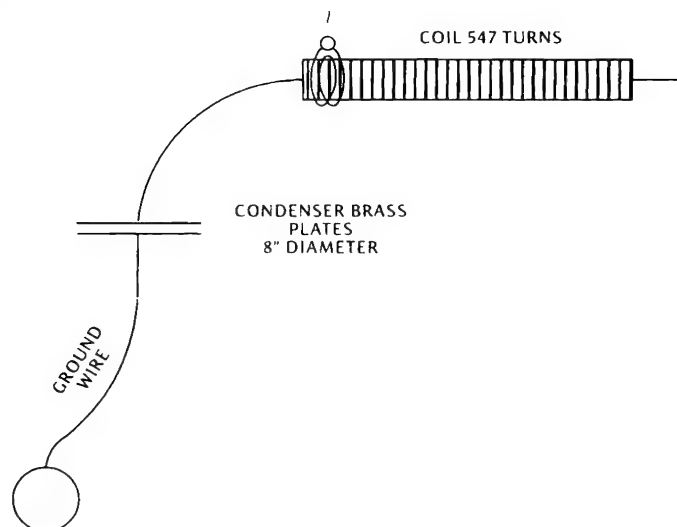
Evidently this is due to the fact that the inductance of the whole is smaller than the inductance of each single part or coil. A conclusion of importance: The greater the number of coils the longer can be each individual coil and this means virtually a greater magnifying ratio. A receiver constructed on lines of above experiment is undoubtedly the best.

Experiments with tuned coils

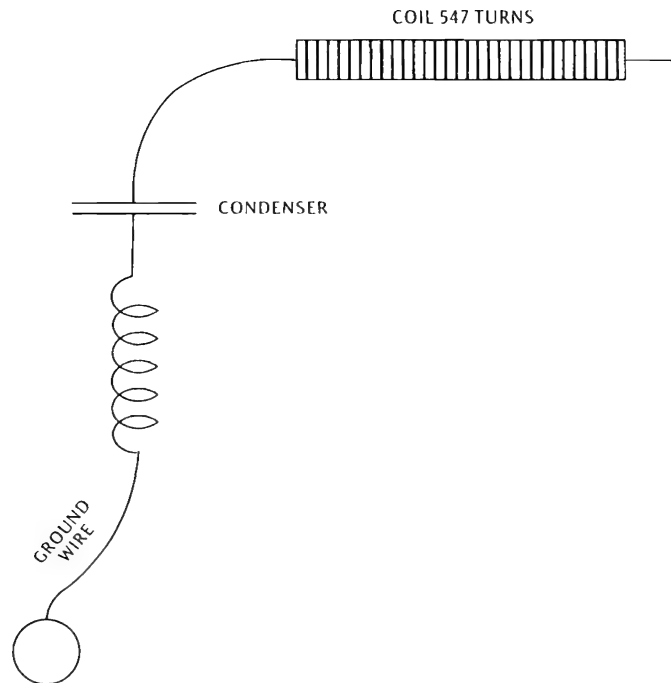


One of the four coils before experimented with, 547 turns each, miniature lamp *I* included, in secondary 3 turns as indicated was used and resonance obtained with $1\frac{1}{2}$ turns of ind. Regul. and one jar in each condenser set.

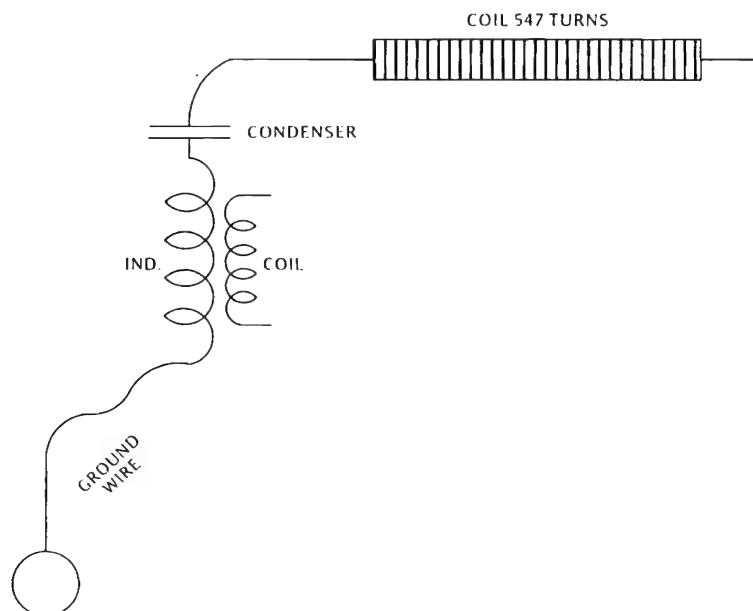
A condenser consisting of two parallel plates, 8" d. of brass was now inserted in series with the coil as shown in sketch and resonance obtained with plates $\frac{1}{8}$ " apart: $1\frac{1}{16}$ turns of regulator, one jar in each set of condensers.



Note: The lamp lighted brighter in this experiment. This may have been due in a small measure to the fact that less turns were used in regul. coil which made the exciting current slightly stronger. The chief cause was probably the condenser which enabled a better and more economical excitation through the ground wire. If this is not so, then I would attribute the greater intensity of the lamp to the capacity effect produced in the coil. Namely the presence of the condenser causes a different distribution of the capacity in the vibrating coil and it is evident that the current closer to the end must be relatively stronger, hence the induction effect upon the secondary on the end nearer to the capacity relatively greater. This will be further investigated. For the present it does not appear that because the lamp lights stronger the system as a whole takes up more energy. The effect may be simply due to the modified distribution of the current in the turns of coil with 547 turns.

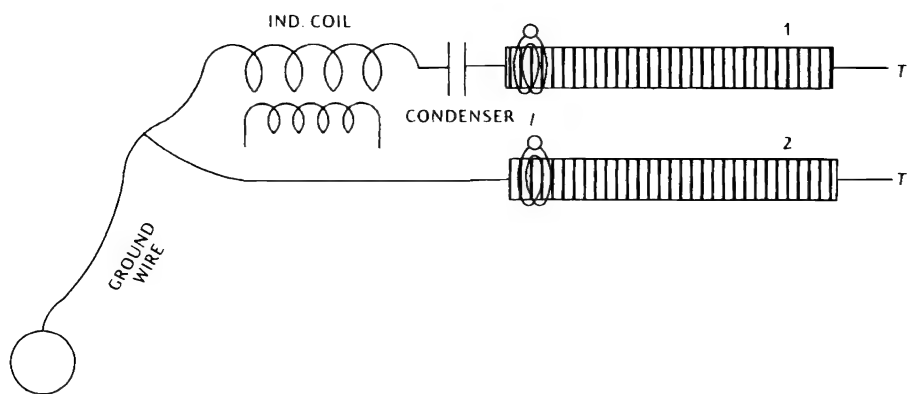


The observation with the condenser in series as above suggests arrangement as indicated in sketch with inductance in ground wire being such that the lower part from ground connection to the lower condenser plate is one quarter of wave length. The coil added should then be one half wavelength or an even number of half wavelength's. Condensers may be inserted between the successive parts. Such arrangements were however experimented with especially in Colorado. (See notes Col.)



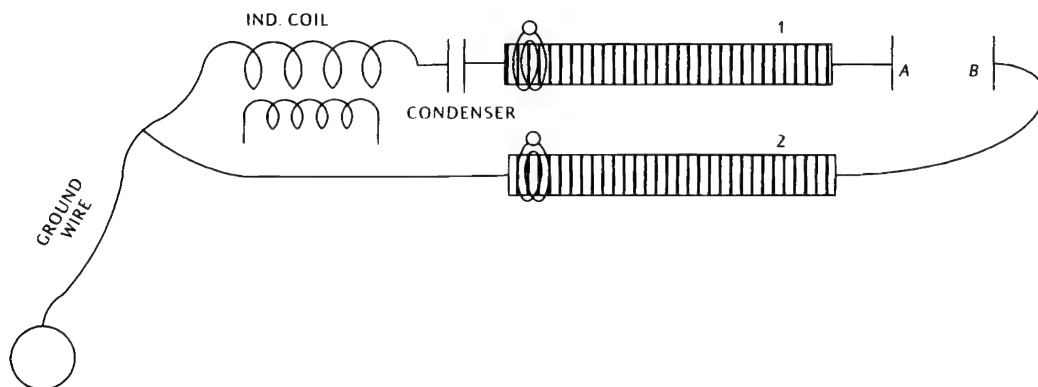
In this experiment the small induction coil before referred to was inserted in the ground wire. Resonance was obtained with: $1\frac{1}{8}$ turns Reg. coil and one jar in each condenser set.

The insertion of the induction coil slowed down the vibration a trifle, otherwise the conditions remained same. The two systems vibrate as one which is the rate of the larger system. If there are independent short oscillations in the small system their effect upon lamp is inappreciable.

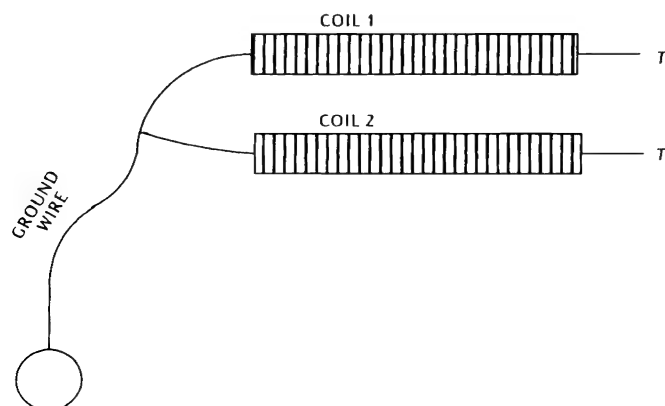


In this experiment the lamp on coil 2 lighted alone. Even with stronger excitation lamp of coil 1 remained dark.

Important to notice: When system 1 as illustrated was used singly and one of the brass plates 8" diam. was attached to terminal *T* it produced scarcely any difference on the lamp, but when the plate was attached to terminal *T* of system 2 the lamp on 2 did not light and could not be made to light with very strong excitation of ground wire.



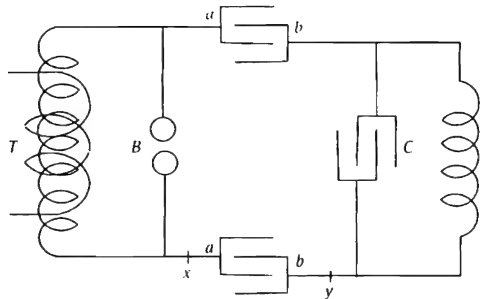
In this experiment when plates *A* and *B* were far apart the lamp of coil 2 did not light. When the plates were gradually brought near, the lamp of this coil began to light and finally when plates were quite close or in contact **both lamps** on coil 1 and 2 lighted exactly well the same as when the two coils were connected in multiple in a previous experiment.



A curious observation was made with two coils in multiple as shown. When one of the brass plates 8" diam. of condenser was connected to terminal *T* of coil 1 lamp of coil 2 lighted. When plate on coil 1 disconnected, lamp on 2 does not light. When coil 1 disconnected, lamp of coil 2 lights. These phenomena can be easily explained. The investigation will be followed up.

July 13, 1901

When using connection as indicated in diagram below curious observations are made which raise a doubt as to the amount of energy consumed on either side of the condenser when one side includes a spark gap and the other has none.



Obviously more energy is consumed on left side of condensers *ab ab* that is on side to which coatings *a a* are connected because the current of the secondary of transformer *T* passes through the arc *B*.

There may be, however, other causes, as the giving off from the arc of short waves. These statements assume that the circuit is otherwise symmetrical to the condensers *ab ab*.

As bearing on above following experiments were made:

1) A coil of 3 turns № 10 wire, 4" diam. was wound on top of which more turns of thinner wire serving as secondary were placed. This secondary included a miniature lamp requiring minute current. A fixed quantity of energy was supplied from transformer *T* to condensers *ab ab*. The primary circuit – that is the three turns – of the induction coil was first inserted in series with the spark gap and coatings *a a* on place marked *x* and then at *y* in the part of the circuit not including the spark gap but simply coatings *b b* and condenser *C*. The lamp lighted the same, took equal amount of energy as far as could be ascertained.

2) The e.m.f. on secondary of small coil was the same in both cases but this did not settle doubt for the frequency might have been different owing to harmonics chiefly on one side. The condenser *C* was much larger than *ab ab*. The frequency considered in its totality might have been smaller on right side and current proportionately stronger, hence e.m.f. on secondary of small induction coil the same as before. The coil was replaced by an iron wire and again the same result was obtained.

3) Inductance coil *L* was now connected but although it modified greatly the distribution of the current in the main and branch circuit the iron wire was affected equally at both places *x* and *y*.

Conclusion: Total energy consumed may be different in the both sides although perfectly symmetrical if one contains arc and the other not, irrespective of the arc itself. A delicate test is to be applied.

Tank I			Tank II		
Jar №	Capacity expressed in microfarads centimeters		Jar №	Capacity expressed in microfarads centimeters	
1	0.0193	17,340	7	0.0209	18,810
2	0.0182	16,380	8	0.0190	17,100
3	0.0180	16,200	9	0.0185	16,650
4	0.0190	17,100	10	0.0200	18,000
5	0.0196	17,640	11	0.0245	22,050
6	0.0200	18,000	12	0.0191	17,190
Total from measurement of individual jars	0.1141	102,690	Total from measurement of individual jars	0.1220	109,800
Total from measurement of tank as a whole	0.1158	104,220	Total from measurement of tank as a whole	0.1228	110,520

Capacity of Tanks I and II in Series

Value derived from	Capacity expressed in	
	microfarads	centimeters
Measurement of individual jars	0.0581	52,290
Measurement of each tank separate	0.0596	53,640
Measurement of tanks in series	0.0582	52,380

Capacity of condensers with the two tanks connected in series

Tank I	Tank II	Capacity in μF	Capacity in cm
Jars 1	Jars 7	0.0100 μF	9000 cm
" 2	" 8	0.0093 μF	8370 cm
" 3	" 9	0.0091 μF	8190 cm
" 4	" 10	0.0097 μF	8730 cm
" 5	" 11	0.0110 μF	9900 cm
" 6	" 12	0.0098 μF	8820 cm
" 1,2	" 7,8	0.0193 μF	17370 cm
" 1,2,3	" 7,8,9	0.0284 μF	25560 cm
" 1,2,3,4	" 7,8,9,10	0.0381 μF	34290 cm
" 1,2,3,4,5	" 7,8,9,10,11	0.0491 μF	44190 cm
" 1,2,3,4,5,6	" 7,8,9,10,11,12	0.0589 μF	53010 cm

July 13. 1901



Capacity
of condensers with the two tanks connected in Series

Tank	I.	Tank II.	Capacity in M.F.	Capacity in C.M.
Jars	1	Jars 7	0.0100	9000 "
"	2	" 8	0.0093	8370 "
"	3	" 9	0.0091	8190 "
"	4	" 10	0.0097	8730 "
"	5	" 11	0.0110	9900 "
"	6	" 12	0.0098	8820 "
<hr/>			0.0193	17370 "
"	1, 2	" 7, 8	0.0284	25560 "
"	1, 2, 3	" 7, 8, 9	0.0381	34290 "
"	1, 2, 3, 4	" 7, 8, 9, 10	0.0491	44190 "
"	1, 2, 3, 4, 5	" 7, 8, 9, 10, 11	0.0589	53010 "
"	1, 2, 3, 4, 5, 6	" 7, 8, 9, 10, 11, 12	0.0689	62010 "

Capacity Average

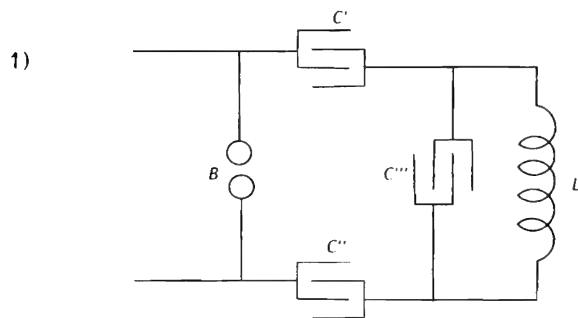
1 jar in each tank -	0.009740 M.F.	8766 C.M.
2 " " "	0.01948 "	17532 "
3 " " "	0.02922 "	26298 "
4 " " "	0.03896 "	35064 "
5 " " "	0.04870 "	43830 "
6 " " "	0.05844 "	52596 "
Average value of one jar in tank I.	0.0190 "	17100 "
" " " " II	0.0200 "	18000 "

Tank I	Tank II	Capacity in μF	Capacity in cm
Capacity average			
1 jar	in each tank	0.009740 μF	8766 cm
2 "		0.01948 μF	17532 cm
3 "		0.02922 μF	26298 cm
4 "		0.03896 μF	35064 cm
5 "		0.04870 μF	43830 cm
6 "		0.05844 μF	52596 cm
Average value of one jar in tank I		0.0190 μF	17100 cm
Average value of one jar in tank II		0.0200 μF	18000 cm

July 13, 1901

From old notes

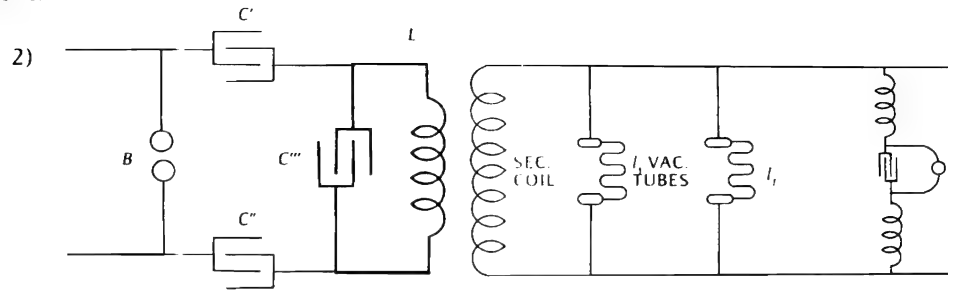
Following arrangements of apparatus offer specific advantages particularly in cases when only high frequencies are desirable. Diagram 1 illustrates ordinary arrangements of condensers C' C'' make and break B and conductor L . In the present modification the conductor is shunted by a condenser C''' and in this way two circuits are formed. By varying the capacities and inductances in the two circuits very striking effects are obtained especially by observing proper rules of tuning.



Enormous electromotive forces per unit length of conductor L are obtainable and also currents which may reach many hundreds of thousands of amperes. To produce such currents it is necessary to construct condenser C''' of copper or aluminium sheet as tinfoil melts. I construct conductor and condenser in one, so that there is no joint except at the ends to the coatings of the condensers C' C'' which are the outer coatings and of heavy metal. It is astonishing that with say twenty turns of conductor L – the turn about 1 foot diameter a bulb 1 foot diameter, exhausted as high as practicable with my mercury pump, is lighted up by induction and the gas inside brought instantly to a very high temperature. It is not **absolutely** necessary to tune the circuits in this arrangement, for the circuit can be forced through conductor L simply by reducing its impedance. I find that in this form of apparatus a relatively very intense higher note can be obtained. For the best performance of course the two circuits should be tuned to the same fundamental note. In this case L must be just half the wavelength. It may be however adjusted for the next octave and as above stated the results are surprisingly good. A peculiar advantage of the arrangement in diagram 1. is that the current through the make and break B may be very small as compared with that through conductor L . This is sometimes a great improvement but not necessarily

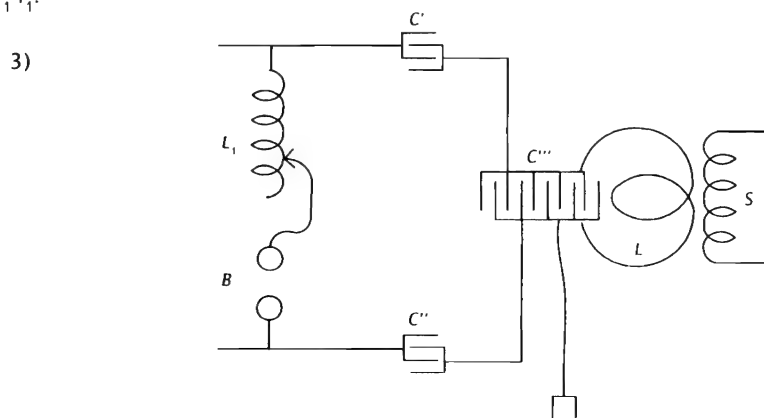
so in all forms of my apparatus. With mercury interrupters the resistance at B can be reduced as far as desired.

A very great practical advantage is however that the condenser C''' may be an ordinary mica condenser but constructed as before indicated of copper or aluminium sheet. I calculate the condenser and inductance L for the frequency of the oscillation through B . The circuit LC''' I connect to ground so that despite of great tension on the condensers C' C'' perfect safety results. A secondary coil may then be used for running lamps through the building or other purposes. The diagram 2 illustrates this special arrangement.



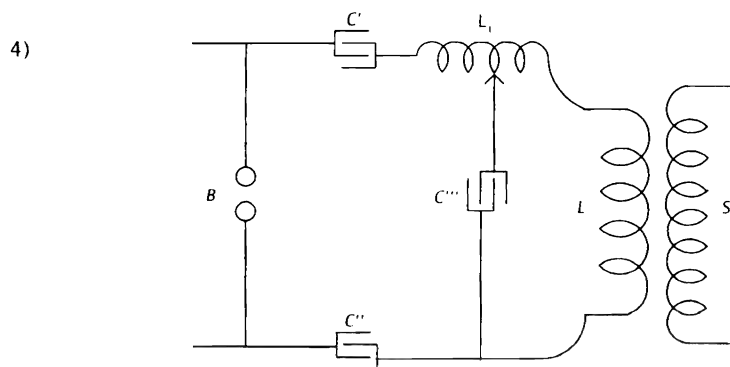
Here C' C'' are condensers of small capacity, C''' condenser for small pressure large capacity, L stout short conductor.

The secondary S may also be connected to ground if desired. The condenser C''' is of course protected by conductor L otherwise it could not withstand the strain. The coil L keeps the pressure at the terminals of C''' as low as desired. When the condenser C''' is also of small capacity then L has many turns and in this case I generally convert down so that the secondary S has a fewer, or perhaps the same number of turns, at any rate a number of turns dictated by the requirements of circuit which the secondary S supplies. In such a case the secondary is invariably connected to the ground. If it is desired to connect the coil L also to ground in case it has many turns the middle point should be connected otherwise the circuit would be asymmetrical or of the form of grounded circuits used in my system of transmission through natural media. The secondary should then be arranged relative to the primary L in the ways indicated in my previous records of this kind of apparatus. These arrangements last described give very good results with vacuum tubes because of high frequency and also on account of small damping of oscillations in circuit LC''' . The secondary S should also be tuned to LC''' so that preferably all these circuits are vibrating the same note. I also tune the individual circuits supplying the lamps or devices I, I_1, I_2 .



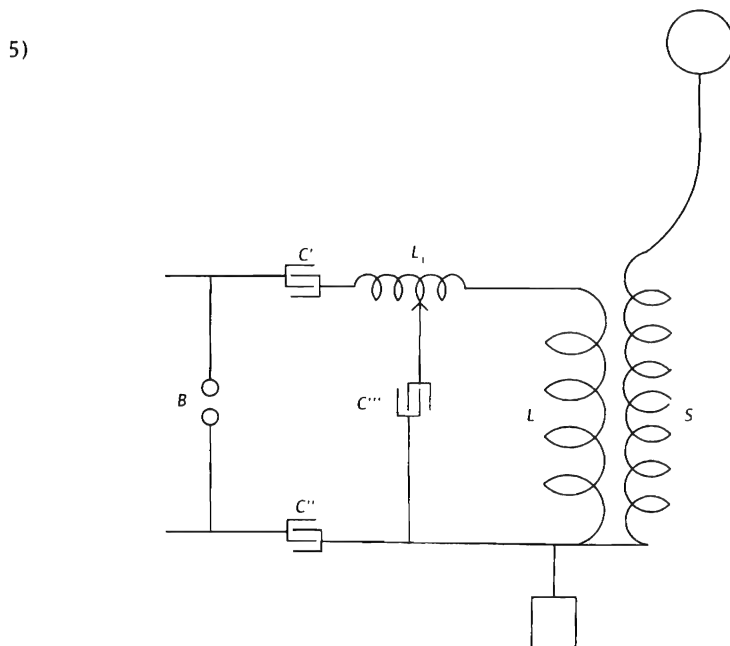
To prolong the oscillations through device B the inductance in circuit $C'B C''$ is increased. This can be done without departing from the high frequency because the tension of the source can be very high and condensers C' C'' very small, hence inductance considerable. The diagram 3. illustrates modified apparatus in one of its forms.

By making the inductance L_1 very large the oscillations may be greatly prolonged and particularly when the circuit $C'''L$ is tuned to the same note a great advantage is so secured.



In diagram 4. is shown a modification of diagram 3. which I find suitable in the instances especially when the capacity C''' is likewise small. It is very easy to tune the circuits merely by shifting the contact point c of one of the terminals of the condenser C''' and inductance L .

The last described modification is very good in connection with transmission through natural media in accordance with my system. I use this arrangement as shown in diagram 5.

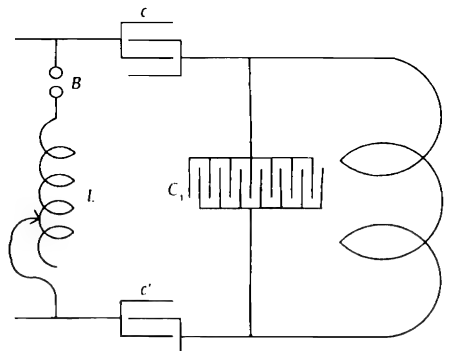


For the sake of simplicity the condenser C'' is not employed. The transmitter S with capacity C'' is in this form very effective. The circuit through B is traversed by a small current and the oscillation in it, owing to small damping and great momentum persists very long after each closure of device B . The circuit LC''' being sharply tuned to same note magnifies the movement greatly during the oscillation through B . When however the circuit through B is interrupted the oscillations through L continue long. All this contributes to the intensity of the movement obtained in the system SC'' .

Other modifications to follow.

July 15, 1901

Design of condenser to be used in shunt to a coil or loop of inappreciable resistance, for the purpose of obtaining currents of very high frequency, great intensity and persisting very long.

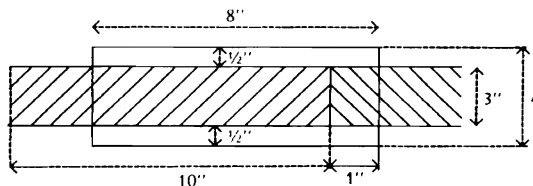


Theory. When the local circuit $C_1 l$ formed as indicated in diagram, vibrates in unison with main exciting circuit $cBLc'$ the impedance of the path $C_1 l$ is reduced to the ohmic resistance which is entirely negligible and hence the vibration of the exciting circuit is merely dependent on the inductance L and capacity of condensers $c c'$. The inductance L reduces the rate of vibration but has the advantage of prolonging the oscillation and producing a greater resonating rise in the local circuit. It is therefore better to use inductance in the exciting circuit. This however is easily practicable without great sacrifice of frequency as the source supplying the energy to condensers $c c'$ can be of very high tension and hence the condensers $c c'$ as small as desired. I shall assume that 10000 cm is the inductance of the exciting circuit which, with all condensers – six in each set – connected, will give a vibration not far from 200000 p. s.

The vibration period of exciting circuit under the conditions above assumed will be $T = 2\pi\sqrt{\frac{c}{2}l}$, $c = c'$, and this must be also the period of the local circuit. Hence $T = 2\pi\sqrt{c_1 l}$ from which $c_1 l = \frac{c}{2}l$. In the present apparatus $\frac{c}{2}l$ (both tanks in series) = 0.0586 μF , L as before assumed (including all connections) = 10000 cm or $\frac{1}{10^5}$ H. Substituting we have $c_1 l = \frac{0.0586}{10^6} \cdot \frac{1}{10^5} = \frac{586}{10^{15}}$.

Here c_1 is in farads and l in Henry's. Taking both in centimeters we shall have $c_1 l = \frac{586 \times 9 \times 10^{11} \times 10^9}{10^{15}} = 5274 \times 10^5$.

Construction of condensers. With very heavy currents as obtainable in this way a tinfoil condenser is of no use. The coatings must be constructed to stand the enormous current and copper or aluminium sheet should be used or also an electrolytic condenser as the main condensers $c c'$ ought to be employed. In fact I think that the latter are best of all. In the present instance for convenience the condenser is to be made of mica and copper sheet as follows:



20 copper sheets $\frac{10}{1000}$ " thick sheet each 10" long 3" wide. Mica 8"× 4" lapping over copper $\frac{1}{2}$ " on each side and 1" on the narrow ends.

There will be 19 plates of mica and 10 copper strips in each of the armatures.

Effective area will be $19 \times 3 \times 6$ sq. inches = $A = 116$ cm sq. Each mica sheet $\frac{15}{1000}$ " thick, hence $d = 0.038$ cm. Taking for this mica sp. ind. capacity = 6 we have:

$$C_1 = \frac{19 \cdot k \cdot A}{4\pi d} = k \cdot \frac{116 \times 19}{12.57 \times 0.038} = k \cdot \frac{2204}{0.478} = 6 \times 4611 = 27666 \text{ cm.} = 0.0307 \mu\text{F.}$$

With reference to above equation we have $c_1 l = 5274 \times 10^5 = 27666 l$ from which

$$l = \frac{5274}{27666} \cdot 10^5 \text{ centimeters} = 19063 \text{ or roughly } 19000 \text{ cm.}$$

Taking a coil of diameter of about 13" stout wire for lighting a large bulb 12" diameter etc. one turn will have not far from 4000 cm and two turns close together will probably have not far from above value. Conclusion: Two turns on a trifle larger diam. are to be used.

— . —

When a wire is stretched out straight it has a certain capacity given by formulas. So if it be cylindrical and of length l the capacity c_1 will be $c_1 = \frac{l}{2 \log_e \frac{l}{r}}$. Usually however it has not the value given by

this formula, for if it be placed vertical the capacity increases with the elevation and on the other hand if it be stretched horizontally it has a capacity with reference to the Earth's surface. Suppose it is placed above ground at a distance d from the same then it has a capacity $c_2 = \frac{l}{2 \log_e \frac{2d}{r}}$. These two are equal when $\frac{2d}{r} = \frac{l}{r}$ or $l = 2d$.

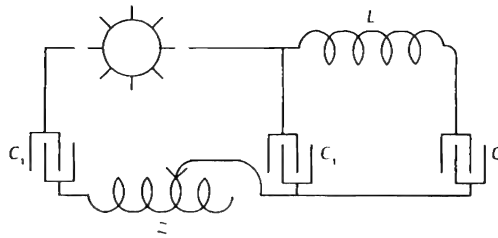
In my system of transmission by conduction with grounded circuit the effective capacity is $\frac{c_1}{c_1 + c_2}$.

This has been demonstrated in many experiments. Hence it is of great importance 1) to reduce the capacity with reference to other objects and 2) to elevate the wire as the capacity increases with height at a rate of about $\frac{1}{2}$ of one percent per foot.

If the same wire be coiled up it may have a smaller or greater capacity. This will also depend on the diameter of the coil. When wound on a coil the wire acquires an other capacity which grows in proportion to the square of the diameter as shown in Colorado experiments from which practical formulas have been derived. But while the wire is cramped in a smaller space the capacity designated c_1 diminishes so that the capacity of a coil is normally much smaller than that of the wire stretched out. But if the diameter be very large then the capacity of the coil may be much greater. This is important to consider in constructing rigid electrical systems.

July 20, 1901

Experiments with condenser in shunt to part of primary discharge circuit of large laboratory apparatus.



In this case L was inductance of the two turns of cable (in series) contained in square frame $8' \times 8'$, frequency referred to. L is the self-induction regulator.

- 1) $C_1 C_1$ three jars each $C_1 = 3 \times 0.0195 = 0.0585 \mu\text{F}$.
 C 2 jars $C = 2 \times 0.0195 = 0.039 \mu\text{F}$.

Capacity in branch C_2 from equation:

$$\frac{1}{C_1} + \frac{1}{C} = \frac{1}{C_2} = \frac{C + C_1}{CC_1} = \frac{\frac{2}{3}C_1 + C_1}{C_1^2} \text{ from this } C = \frac{2}{3}C_1, C_2 = \frac{3}{5}C_1.$$

Now resonance was obtained with $L = 6\frac{3}{4}$ turns. In this case the impedance of the condenser and inductance path was just equal to Ohmic resistance i.e. negligible. The capacity in primary exciting circuit was thus C_1 and total inductance $L = 6\frac{3}{4}$ turns and connections. We have then

$$C_2 L = C_1 L \text{ or } L \cdot \frac{3}{5}C_1 = C_1 L \text{ from which } L = \frac{5}{3}L.$$

Taking from tables value of $L = 6\frac{3}{4}$ turns = 20000 cm approximately $L = \frac{5}{3} \cdot 20000 = 33000$ cm about. It should be 32000 cm.

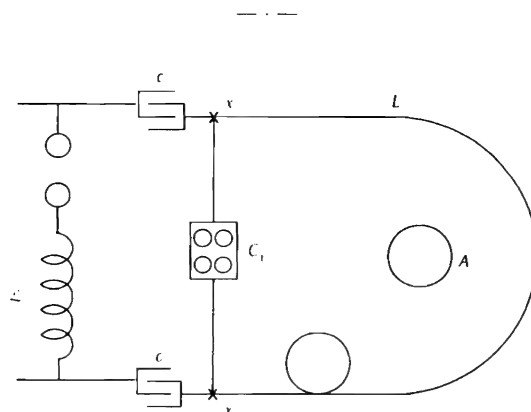
2) $C_1 C_1$ each	two jars,	C one jar	Resonance	$6\frac{3}{4}$ turns of L as before.
3) $C_1 C_1$ "	"	C three jars	"	$8\frac{1}{4}$ " L "
4) $C_1 C_1$ "	three "	C one jar	"	$4\frac{1}{4}$ " L "
5) C_1 (left)	2 jars,	C_1 (right) three jars; C one jar	"	$5\frac{3}{4}$ " L "
6) $C_1 C_1$	one jar	C one jar	"	$7\frac{3}{4}$ " L "
7) $C_1 C_1$	two jars	C two jars	"	7 " L "
8) $C_1 C_1$	three "	C three	"	7 " L "

— . —

1) $C_1 C_1 C$	one jar each	Resonance with	$11\frac{1}{2}$	"	L	"
2) " " "	two jars "	"	$10\frac{1}{2}$	"	L	"
3) " " "	three "	"	$9\frac{1}{2}$	"	L	"
4) " " "	four "	"	$8\frac{1}{2}$	"	L	"
5) " " "	five "	"	$7\frac{1}{2}$	"	L	"
6) " " "	six "	"	$6\frac{1}{2}$	"	L	"

Note: Evidently no change in relation when the ratio of capacities in both the circuits is kept the same. The diminishing number of turns with increasing number of jars is in all probability due to the smaller inductance when all jars connected. This is to be verified.

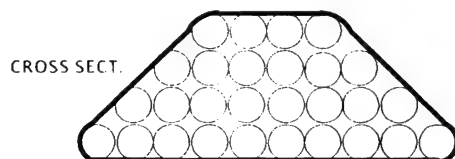
Data for reference



L cable around laboratory, C_1 condenser in shunt, L Regulating inductance coil, A coil in center of room. The constants of circuit $L \ c \ c \ L$ were adjusted until resonance was obtained in coil A . This took place when there were 13 turns of Reg. Ind. coil in circuit and 6 jars in each condenser set.

C_1 four old jars in multiple.

Particulars relative to coil for exciting large vacuum bulb etc. Okonite wire № 10 wound around a form. Cross section as in sketch 18 turns, mean diameter of coil about 14". This coil was connected to points $x \ x$ instead of cable L . Resonance was obtained with $16\frac{1}{4}$ turns of Reg. Coil L 6 jars in each set of condensers, C_1 as before.



In this case condensers $c \ c = 0.0582 \ \mu\text{F}$ $C_1 = 0.01$ about.

The inductance L with connections was about 56000 cm from tables. From this approximate inductance L of coil of Okonite wire would be $0.0582 \ L = 0.01 \ L$, $L = 326000$ cm.

Test of large spiral coil with ground wire excitation for purpose of ascertaining influence of ball 8" diam. at the free terminal

	Turns in Reg. Coil	Capacity primary
Resonance with ball	7	6 jars each side
" without ball	$6\frac{5}{16}$	6 " "

Large mercury break old casting last modification

diameter of bore between teeth $13\frac{17}{32}'' = 13.53''$

Circumference 42.5"

3 contact streams 16 teeth supported by a common ring hollow for catching the mercury.

The space for one make and one break if both equal would be $\frac{42.5}{96} = 0.4427''$.

Conclusion: Teeth and outlet rods for streamers are to be on face $\frac{1}{4}''$ wide.

Stationary waves will be useful in connection with light houses, ocean liners etc. as they enable to ascertain the direction from which disturbances are coming. The simplest way of producing the waves will be by connecting the oscillating circuit at two points to Earth. For this no powerful apparatus is required. They may be also produced by two oscillating circuits each connected to ground and to an elevated terminal. Stationary waves in a limited region may then be obtained by interference. Very powerful apparatus is necessary if but a single circuit connected to Earth and to an insulated terminal is used. Both the direction and distance of a moving object, as a vessel, may be determined by a circuit carried on the same. It will be best to connect the circuit at two points to the ground or else two circuits each connected to the ground and to an insulated terminal as usual may be employed. The distance may be however approximately determined by using a single circuit tuned and having a resistance in the secondary. This resistance – which still better may be in an independent circuit will be heated less in proportion as the distance from the source of the disturbance increases. The device may be calculated so that the value of the resistance will at once give the distance.

Stationary waves may enable also the height to be indicated. It is quite possible that the waves are reflected and may give nodal and ventral points.

Instead of using stationary waves it will be possible to employ ordinary direct or alternating currents. The generator being connected to two points of the ground direction can be indicated. When using such currents condenser method will be the best. For example with direct currents passing through the ground in a given direction it is possible to charge a condenser during a definite time interval determined by a pendulum or clockwork and from the energy of the discharge the distance from source may be computed. Various arrangements on these lines will be worked out.

July 22, 1901

Approximate estimate of inductance of connections on large apparatus with the two sets of condensers in series as usual, arcs included.

One of the coils before described 547 turns on 3½" core connected to ground through the ground wire 14 feet long gives resonance with 1½ turns Regul. and 1 jar in each set.

Circumference of coil 11", length of wire $547 \times 11 = 6017" = 501.4$ feet. To this ground wire to be added gives $\frac{\lambda}{4} = 516$ feet roughly. Rather more than less. Allowing 4 feet for girder we have about 520 feet = $\frac{\lambda}{4}$. The vibration should be

$$n = \frac{186000 \times 5280}{520 \times 4} = 472000 \text{ p. s.}$$

Calling the inductance of connections L , we have ($C = \frac{0.0195}{2} = 0.00975 \mu\text{F}$)

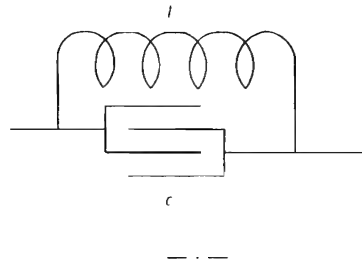
$$\frac{1}{472000} = \frac{2\pi}{10^3} \sqrt{L \frac{975}{10^5}} = \frac{10^3}{472000 \times 2\pi} = \frac{1}{100} \sqrt{L \cdot 97.5} \text{ and from this}$$

$$\left(\frac{100}{472 \times 2\pi} \right)^2 \cdot \frac{1}{97.5} = L = \frac{10^3}{4 \times 97.5 \times 222784} \text{ Henry;}$$

$$L = \frac{100}{39 \times 222784} = \text{approx. } \frac{1}{39 \times 2228} = 11500 \text{ cm.}$$

The Colorado connections had 7300 cm approx. The above amount (11500 cm) is evidently too large because coil has appreciable capacity. This is to be eliminated.

Note: Best result is obtained by tuning system like this, L , C , both known.

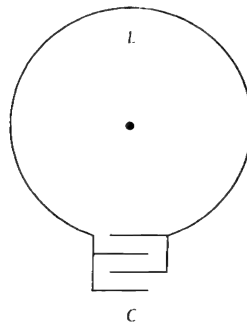


Experiment with condenser and loop to be used in determining vibration. Also for purpose of obtaining very strong current.

Loop 2 feet diam. circular. $r = 30$ cm about.

Wire $\frac{5}{16}$ " diam. $a = \frac{5}{16} \cdot \frac{1}{2} = 0.4$ cm.

Inductance of loop $L = 4\pi r \log \frac{8r}{a} = 1000$ cm roughly.



C condenser mica about $0.031 \mu\text{F}$ (calculated).

The period of system should be:

$$T = \frac{2\pi}{10^3} \sqrt{\frac{1000}{10^9} \cdot 0.031} = \frac{2.14}{10^6}; \text{ from this}$$

$$n = 470\,000 \text{ per sec}$$

The exciting system comprised loop single in square frame and few turns in Regul. coil, 2 jars in each set of condensers of large apparatus all in series. Resonance was obtained with: 3 turns Regul. coil 4 jars in each set.

Capacity of 4 jars in series all four is about $0.005 \mu\text{F}$. From this we may determine the inductance of loop. The inductance in primary was nearly $24000 \text{ cm} = L_p$. Now

$$L_p \cdot 0.005 = Lc = \frac{1}{10^6} 24 \times 0.005 = L \cdot 0.031.$$

Hence $L = \frac{24 \times 0.005}{0.031 \times 10^6} = 4000 \text{ cm}$ approx. Evidently the system was tuned to undertone as inductance of loop is just four times the calculated.

July 30, 1901

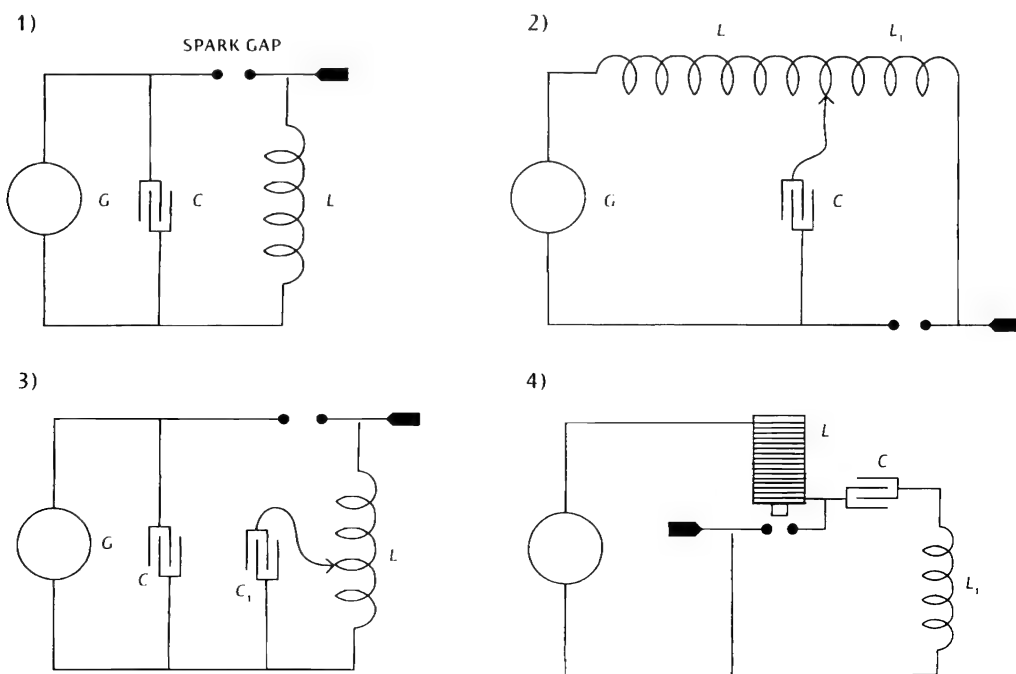
From old notes

Several arrangements have been so far experimented with for the purpose of eliminating entirely the effects of the fundamental disturbance of low frequency which disturb telephones and also limit resonating rise in many cases. It would be desirable to obtain a clear high note from disturbances of much lower frequency such as obtainable by a mechanical break or with a dynamo. It seems out of question to use high frequency dynamos giving vibrations beyond the limit of audition and with mercury breaks or arcs the fundamental discharges can be scarcely more than a few thousand per second.

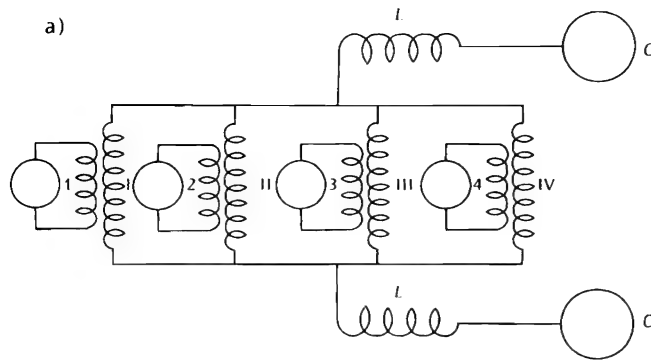
By using a source of continuous pressure, preferably very high, and charging a condenser by the same which discharges under conditions necessary for oscillations, the rates of charging and discharge can be so adjusted that more than 50000 (fifty thousand) individual discharges through a gap are obtained and in this way the effects upon the telephones can be eliminated in a large part if not entirely. A number of arrangements considerably improved over the old, have been experimented with apparently with good success. They are illustrated below:

In 1) the free vibration of system LC is so adjusted as to secure resonance with makes and breaks. The free vibration and fundamental are the same. The source is a high tension rotating transformer G having the high tension winding or it may be any other source of high tension.

In 2) the source G is an ordinary direct current dynamo. The tension is raised by the coil LL_1 , a part of which forms a local circuit with condenser C and gap. The periods of the two circuits are again the same, the adjustment is made by flexible conductor as indicated. In 3) modified arrangement is shown with a source of high tension and local circuit containing no break. In 4) a magnet L is used to blow out the arc and the adjustment is the same as before that is, the circuit including the magnet and condenser is so adjusted that the free oscillation of the system and the fundamental through the gap are the same. The local circuits in 2), 3) and 4) may be of the same or of a higher period, this is not important so long as the above condition is fulfilled. It is always possible to attain the result by proper adjustment of the inductance, capacity and gap or by modifying the e.m.f. until the rates of charging and discharging are such that there is just twice that number of charges which designates the frequency of the free oscillations of the elastic system.

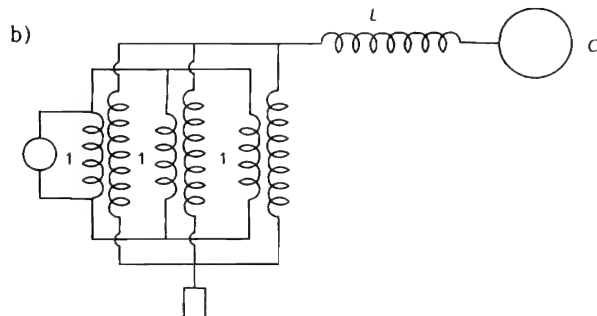


An other line of experiment which is being followed up promises better results. The principle involved may be best explained with reference to diagram a) illustrating one of the arrangements experimented with.



In this diagram 1 2 3 4 ...n are individual circuits, each containing a make and break device. These circuits excite parts I, II, III, IV which in turn excite the whole of system LC .

The inductance LL is sufficiently great to entirely govern the movement or else the circuits LC are independent and tuned to the frequency of the oscillations impressed upon parts I, II, III, IV...n.



When there are many break devices or respectively circuits the chief vibration – that of LC will dominate.

Diagram b) shows a further improvement. Each source (one shown) furnishes currents which differ in phase. To follow up.

— . —

From old notes

Following seems to be a good arrangement in rapid telegraphy etc. either through natural or artificial channels.

A complex of waves or vibrations is sent out from a transmitting station and at the receiving station there are elements each responding to one or more elements of the complex disturbance of the transmitter. The elements of the receiver control contacts which may be in series. Each contact is shunted by a device which is operated when contact is opened by the tuned sensitive circuit. Each of the devices may be used say to print a particular letter of the alphabet. In this way very rapid telegraphy or printing is possible. On each side there may be a typewriter and the message can be directly sent by the typewriter from the transmitting station and printed at the receiving station. It is not difficult to adapt this idea to the ordinary typewriter system.

Aug. 3, 1901

Possible effect of apparatus on Long Island plant

Assume terminal capacity only 4000 cm. If the wood structure does not limit pressure we may expect following:

$$I = E c \omega \text{ Energy} = E^2 c \omega C = \frac{4000}{9 \times 10^{11}} \omega = 6 \times 10^5 .$$

If we take energy in secondary to be 300×750 Watts,

$$E^2 = \frac{300 \times 750 \times 9 \times 10^{11}}{4000 \times 6 \times 10^5} = 10^6 \times 84.38$$

$$E = 9.2 \times 10^3 = 9200 \text{ Volts.}$$

$$\text{Now } I = Ec\omega = 9200 \frac{4000}{9 \times 10^{11}} \times 6 \times 10^5 = 24.75 \text{ Amp.}$$

This current passes through the Earth. Now Energy is contained in each half wave: Hence we have $\frac{300 \times 750}{24.75} = E_1 = 9091 \text{ Volt}$. This means to say that we shall get at two points one half wave length apart theoretically 9091 Volt!

The magnification has no other effect than simply to increase the current through Earth and also proportionately the e.m.f. between two points situated as above. If we have a current of 2475 Amp. the e.m.f. will be 100 times as great, that is – 909100 Volts! This would be great! If the e.m.f. is not dependent on size of conductor – that is a big If! At any rate, the **actual energy** on each unit of area can be only that which is obtained by making ratio of area to area of half wave zone and multiplying by energy of transmitter.

Aug. 19, 1901

(Rewritten from old notes)

India rubber contracts when heated, forming exception to general rule.

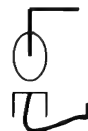
Can odors be transmitted electrically? Will propagation be quickened by cathodic or similar action? If a cup be connected to a pole of a high tension electric source will the odor of a substance placed in the cup penetrate quicker and stronger through space?

There seems to exist a fallacy in the experiments of Joule and Thomson and Gay Lussac with gas escaping through porous plug. In later case only **higher velocity** is given to the gas – but **temperature remains the same**. Methods of detection very sensitive suggest themselves. The telephone, bridge, thermo battery and telephone will show whether actual cooling takes place. The use of an oscillator producing currents in the passage may be resorted to. The mechanical oscillations of a small piston may be thus used to ascertain the amount of work performed.

Principle in refrigeration: Wollaston's Cryophorus seems of practical value. Vapor of water sucked away by machinery will freeze economically. This should be followed up.

Cold mixture of carbonic acid snow dissolved.

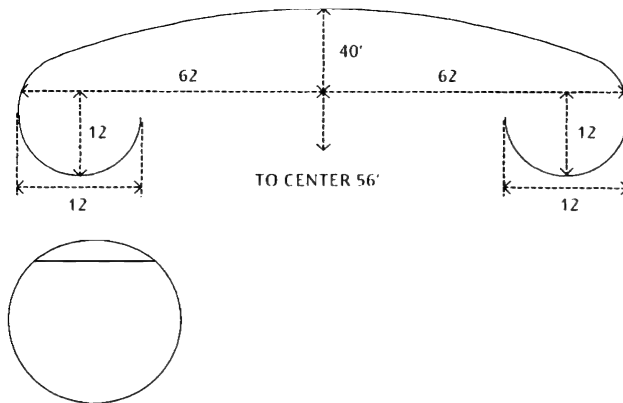
Circuit breaking device: drop in spheroidal state may be interesting



Use always Hydrogen where large capacity of cooling required. Not to forget.

Use of singing flame in connection with telephone for magnifying voice. Interesting.

Aug. 26, 1901



Cupola to be made of spherical surfaces, curvature 4 feet = radius

The above curvature will permit raising the e.m.f. to about 4×10^6 Volts.

Approximate estimate of capacity

Surface of calotte is $s = 2\pi \times 96 \times 40$ sq. feet. This will give roughly $\frac{2\pi \times 96 \times 40}{16} =$ about 1500 squares 4×4 feet curved.

/.... / * tore only outside will be effective. We may take about three rows of curved sheets.

* Illegible – Ed. note

Circumference of large circle is $124 \times \pi$. We will get about $\frac{124 \times \pi \times 3}{4} =$ roughly 300 sheets. Both together will give about 1800 effective sheets. Now the capacity roughly estimated of one of the square sheets may be taken to be in the same ratio smaller than capacity of complete sphere as the surface of the sheet is smaller. The surface of complete sphere 4 feet radius would be $4\pi r^2 - 4\pi \times 16$ and surface of sheet roughly 16 square feet. Hence the ratio $\frac{16}{4\pi \times 16} = \frac{1}{4\pi}$ multiplied with the capacity of such sphere will give the capacity of one sheet. Calling it C we have $C = \frac{1}{4\pi} \cdot r$ in centimeter; r being 4 feet = $4 \times 30 = 120$ cm we have $C = 120 \times \frac{1}{4\pi}$ roughly 10 cm. The total sheet will however not be effective and I think it will be not far from truth to adopt $C = 6$ cm as effective value for each sheet. Calling C the capacity it should be $1800 \times 6 = 10800$ cm. But at a height of 250 feet we should have increase of about $\frac{1}{2}\%$ per foot as determined in Colorado, hence $C = 20000$ cm not less rather more. Accordingly taking $T = \frac{1}{10^5}$ we have $L = 112500$ cm. For $T_1 = \frac{1}{50000}$ $L_1 = 450,000$ cm.

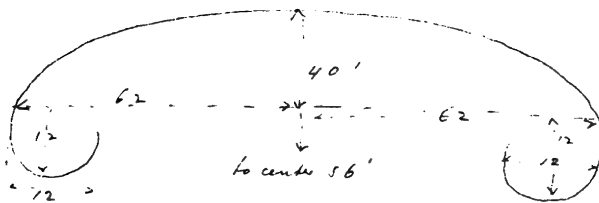
— . —

Assume charge 240 times per sec – at 40000 Volts.

$$240 \times \frac{1}{2} \times 16 \times 10^8 \cdot \frac{1}{4 \times 10^6} = 48 \times 10^3.$$

$$48000 : 750 = 64 \text{ H.P.}$$

Aug. 26. 1901 94



Cupole to be made
of spherical surfaces
envelope 4 feet = radius

The above curvature will permit raising the s.e. to be
about 4×10^6 volts.

Approximate estimate of Capacity

Surface of cupola is $s = 2\pi \times 96 \times 40$ sq. feet. This will give roughly
 $\frac{2\pi \times 96 \times 40}{16} =$ about 1500 squares 4×4 feet curved.

Round iron on outside will be effective. We may take about
three rows of curved sheets. Circumference of large circle
is $124 \times \pi$. We will get about $\frac{124 \times \pi \times 3}{4} =$ roughly 300 Sheets.

Took together will give about 1800 effective sheets. Now

the capacity roughly estimated of one of the sphere sheets
may be taken to be the same value smaller than

capacity of complete sphere on the surface
of the sheet is smaller. The surface of complete
sphere 4 feet radius would be $4\pi r^2 = 4\pi \times 16$ and surface
of sheet roughly 16 square feet hence the ratio $\frac{16}{4\pi \times 16} = \frac{1}{4\pi}$ multiplied
with the capacity of such sphere will give the capacity of one
sheet. Calling it C we have $C = \frac{1}{4\pi}$ or 2 combinations

if being 4 feet = $4 \times 20 = 120$ C.A. we have $C = 120 \times \frac{1}{4\pi}$ roughly = 10 C.A.

The total sheet will however not be effective and I think
it will be not far from truth to adopt $C = 6$ C.A. as
effective value for each sheet. Calling C the capacity

it should be $1800 \times 6 = 10800$ C.A. This at a height of
250 feet we should have increase of about $\frac{1}{2}\%$ per foot as
determined in calculations hence $C = 20000$ C.A. not less rather more

Accordingly taking $T = \frac{1}{10^6}$ we have $L = 112500$ C.M. for $T = \frac{1}{50000}$ $L = 450000$ C.M.

Note. Here occurs idea of using arcs in series and determining their number so that arcs will persist just during the required time intervals. Experiment will show how long arc on transformer persists when electrodes separated after the arc has jumped. Suppose the length with 40000 Volts to be l . Then if n be the number of arcs each will have length $\frac{l}{n}$. This enables to calculate n so that arc persists during required time interval. For if disk rotates with velocity v then length $\frac{l}{n}$ will require $\frac{l}{nv}$ parts of a second. C is known and v also, hence n can be determined from previous experiment. The great number of arcs is however objectionable on account high resistance as arc lengthens. Better always short arc: Closure not until the electrodes are close and opening sudden when electrodes are still close. This would seem commendable employment of air blast outside of disk. Good idea.

Aug. 28, 1901

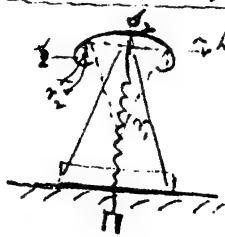
Note relative to transmission of energy through Earth without wire

Stationary waves and other phenomena and facts derived show that by my transmitter, when radiation negligible, the entire energy of the same can be recovered at the Earth's surface.

Assume 300 H.P. be used on my plant that is a supply of energy at a rate of 300×750 Watts approximately then roughly the energy received per square foot of Earth surface – assuming further uniform distribution for the moment – will be $\frac{300 \times 750}{4\pi(4000 \times 5300)^2} = \text{about to } \frac{4}{10^7}$ Watts per each 10000 square feet of surface. This much energy could be received by using an insulated roof 100×100 feet on any point of the globe and passing the current from Earth to roof through a device properly constructed. Theoretically, it is interesting to note that $\frac{12 \times 4000 \times 4000 \times 5300 \times 5300}{10000} = 537 \times 10^9$ instruments could be operated, each consuming energy at the above rate.

The energy however will be supplied from my apparatus at a much higher rate than from dynamo for the condensers discharge in a much shorter time interval. Suppose the plan proposed is adopted and condensers charged 480 times per sec. Three waves being used differing in phase ($0^\circ, 45^\circ, 90^\circ \dots$) there will be 480 discharges and 480 charges, hence energy delivered will be at least doubled, losses in apparatus neglected. At any rate 25% could be safely added. The transformers however can be easily overloaded during the short intervals succeeding each other. It is easy to get energy delivery at a rate of $1000 \times 1000 = 10^6$ Watts from same apparatus, since it serves intermittently. For instance we may use large condensers. It is not unreasonable to expect from these facts alone a delivery rate of actual energy of $4 \times \frac{4}{10^7} = \frac{16}{10^7}$ Watts – in fact $\frac{2}{10^6}$ Watts. Considering however that waves are formed along the Earth surface and the energy is transmitted from one to another position, as demonstrated in Colorado, we shall get with 100 000 per second on equatorial belt $\frac{S}{s}$ times the energy rate = $\frac{12 \times 4000 \times 4000}{24000} \cdot \frac{2}{10^6} = \frac{16}{10^3}$ Watts. In average zone $\frac{32}{10^3}$ Watts and in the region of polar cap, spot 100 miles from pole, something like $\frac{6}{10}$ W and on cap 96 Watts, with circuit still more.

Transmission of energy for purposes of wireless telegraphy " Sept. 8, 1901.



Assume roof as now proposed with plates of 1 meter curvature. The active area may be taken as equal to $S_1 + S_2$. Now $S_1 = 2\pi r_1 h$ and $S_2 = \pi r_2 u$ u being mean circumference of toroidal surface S_2 . As now planned $u = 112$ feet $r_1 = 96$ feet $h = 34$ feet from this

$$S_1 = 6.28 \times 96 \times 34 = 20500 \text{ feet square approx.}$$

$$S_2 = 3.14 \times 6 \times 112 = 2100 \text{ " "}$$



Surface active $S_1 + S_2 = 22600$ square feet about.

If we make half-sphere pieces about 1 meter curvature each must take the space of about 9 square feet, hence we would have $\frac{22600}{9} = 2500$ such half spheres. The spacing of one sphere of diameter as above would be at small height 100 c.m. If half the sphere it would be 50 c.m. but as a matter of fact we can get about an inch more than 20 c.m. each. Suppose this value be nearly correct at such height we should have spacing of whole structure or roof $2500 \times 20 = 62000$ c.m. and at a height of 200 feet certainly not less than 100000 c.m.

On the basis of above estimate if I were to adopt 50000 feet squared I would have

$$\frac{1}{5 \times 10^5} = \frac{2\pi}{10^5} \sqrt{\frac{10^5}{9 \times 10^5}} L \text{ and } \left(\frac{2\pi}{2.5 \times 10^5} \right)^2 = L = \frac{9}{10^5} \text{ being } \underline{90000 \text{ c.m.}}$$

General considerations relative to transmission of energy by conduction through Earth with my system

The problem in any given case is to displace a certain quantity of electricity per unit of time. This quantity should be the largest possible with the means at disposal. Here then is the first practical limit – the quantity given. Calling it Q we have $Q = Pc$. From the equation it follows that for a fixed value of Q , the greater c the smaller will be the potential P . This in itself imposes no limitation as to P , in fact it may be sometimes better to work with a small P and make c very large. But we must remember that the density imposes a limit. Now the density $D = \frac{Q}{S} = \frac{Pc}{S}$, s being the surface of the free terminal. Evidently then if D stands for the maximum practical density which it should be an object to attain within a rea-

sonable limit, then P will be all the greater the greater $\frac{c}{S}$. * This means to say that to get high pressure c should be small. Logical conclusion is that sphere best to employ. It should be furthermore as high in the air as possible. The sphere has least metal, largest pressure or effect, the system is rigid. Following is useful to remember:

* i.e. the smaller $\frac{c}{S}$

$$D = \frac{Pc}{S} \text{ for insulated terminal and } d = \frac{pC}{S} \text{ for Earth.}$$

Now $S = 4\pi R^2 C = R$ hence:

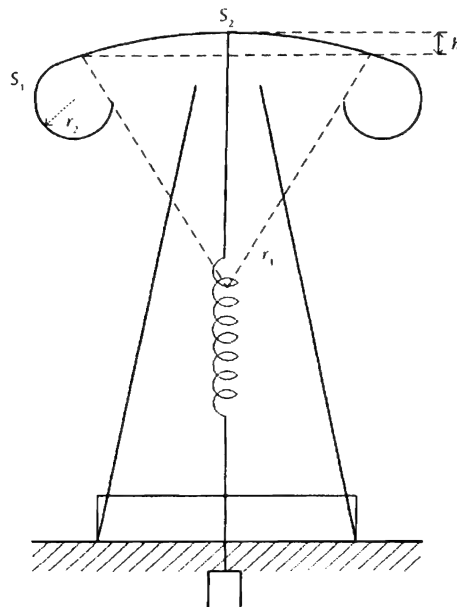
$$\frac{Sd}{C} = p = d \cdot 4\pi R \text{ now } pR = d \cdot 4\pi R^2 \text{ but } pR = Pc = Q.$$

Therefore $Q = dS$ and $Q = Ds$. From this follows

$$D : d = S : s$$

Sept. 8, 1901

Transmission of energy for purposes of "Welttelegraphie"



Assume roof as now proposed with plates of 1 meter curvature. The active area may be taken as equal to $s_1 + s_2$. Now $s_1 = 2\pi r_1 h$ and $s_2 = \pi r_2 u$, u being mean circumference of toroidal surface s_2 . As now planned

$u = 112$ feet, $r_2 = 6$ feet, $r_1 = 96$ feet, $h = 34$ feet. From this

$s_1 = 6.28 \times 96 \times 34 = 20500$ feet square approx.,

$s_2 = 3.14 \times 6 \times 112 = 2100$ " " " .

Surface active $s_1 + s_2 = 22600$ square feet about.

If we make half-spherical pieces about 1 meter curvature each would take the space of about 9 square feet, hence we would have $\frac{22600}{9} = 2500$ such half spheres. The capacity of one sphere of diameter as above would be at small height 100 cm. Of half the sphere it would be 50 cm but as a matter of fact we can not count on more than 25 cm each. Suppose this value be nearly correct at small height we should have capacity of total structure on roof $2500 \times 25 = 62500$ cm and at a height of 200 feet certainly not less than 100000 cm.

On the basis of above estimate if I were to adopt 50000 per second I would have

$$\frac{1}{5 \times 10^4} = \frac{2\pi}{10^3} \sqrt{\frac{10^5}{9 \times 10^5}} L \quad \text{and} \quad \left(\frac{3}{2\pi \times 50} \right)^2 = L = \frac{9}{10^5} \text{ Henry} = 90000 \text{ cm.}$$

Now with 50000 per sec. $\frac{\lambda}{2} = 1.86$ miles = 9820 feet approx.

Equatorial belt would be: $8000 \times 5280 \times \pi \times 9820$.

If we assume the roof to be in the form of a sphere of same capacity it would be of a radius = 1000 meters. The surface of this would be taking feet $3280 \times 3280 \times \pi \times 4$.

The ratio of the small to the large surface (equatorial belt) would be:

$$\frac{3280 \times 3280 \times \pi \times 4}{8000 \times 5280 \times \pi \times 9820} = \frac{328 \times 328}{20 \times 5280 \times 9820}$$

This ratio would also be the ratio of the pressure on the roof to the impressed pressure on ground. Suppose we had on roof only 500 000 Volts we would have on equatorial zone:

$$\frac{328 \times 328 \times 500000}{528 \times 982 \times 2000} = \frac{328 \times 328 \times 500}{2 \times 528 \times 982} = 52 \text{ Volts nearly.}$$

This would be the impressed e.m.f. and could be easily raised to a 200 times higher value.

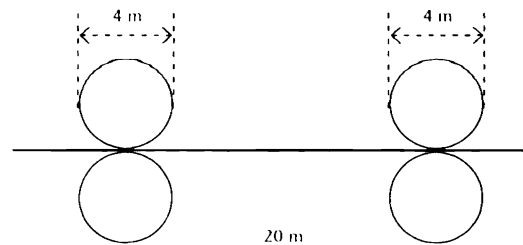
The current in transmitting terminal would be:

$$I = EC\omega = 500000 \times \frac{10^5}{9 \times 10^{11}} \cdot 50000 \times 6.28 = 17500 \text{ Amp.}$$

For the time of closure – certainly too great.

Sept. 18, 1901

Following results may be confidently expected with smaller tower 200 feet and terminal roof of cheap construction as last designed. The roof will comprise a single platform with spherical bodies of large curvature on rim. The construction of latter will be given in detail. The platform 20 meter diameter, 15 round surfaces on top and 15 on bottom as shown in sketch below. It is difficult to estimate in advance the capacity of the structure with precision but an approximate idea may be obtained.



The spherical bodies will be made of a capacity of 200 cm. This would give $30 \times 200 = 6000$ cm without taking elevation into consideration. But owing to proximity capacity will be much smaller. Estimates place the minimum value at not less than 1000 cm (elevation not considered). This means to say that of each spherical body only $\frac{1}{6}$ of the surface is fully utilized. Now surface of one spherical

body will be $\pi \times 400^2$. Calling σ density we would have on $\frac{1}{6}$ of surface $\frac{\pi \times 400^2}{6 \times 3 \times 10^9} \sigma$ Coul. of electricity.

We can safely make $\sigma = 10$ minimum. This would give on the whole structure $\frac{\pi \times 400^2 \times 10 \times 30}{6 \times 3 \times 10^4} =$ roughly

at least $\frac{8}{10^3}$ Coulombs. Now if we put capacity as 1000 cm we would have

$$\frac{8}{10^3} = \frac{1000}{9 \times 10^{11}} V \text{ and } V = \frac{9 \times 8 \times 10^{11}}{10^6} = 7,200,000 \text{ Volts.}$$

This estimate is surely small and we may take safely 10 000 000 Volts with 1000 cm capacity.

Considering simply Earth as ball and leaving out short waves we have since $cP = Cp$
 $V = P = 10^7$ Volts $c = 1000$ cm. $C =$ capacity of Earth $= 636 \times 9 \times 10^5$, $\frac{1000}{9 \times 10^{11}} P = \frac{636 \times 9 \times 10^5}{9 \times 10^{11}} p$. $p =$ roughly 16 Volts. This means variation $2p = 32$ Volts all over globe.

— . —

Results to be expected on bases of preceding with waves of about 2 miles length.

The minimum effect will be on equatorial belt. Area of belt will be $\pi \times 8000 \times 5300$ square feet.

Effective area of roof terminal as assumed before $\frac{\pi}{6} \times 12^2 \times 30$ sq. feet. Since the voltages will be inversely as the areas we shall have:

$$\frac{\pi}{6} \times 12^2 \times 30 : 8000 \times 5300 \times \pi = x : 10^7$$

$$72 : 800 \times 5300 = x : 10^7$$

$$x = \frac{72 \times 10^7}{8 \times 53 \times 10^4} = \frac{72000}{424} = 170 \text{ Volts roughly,}$$

or total variation 340 Volt. From this at the average parallel circle or belt we may expect to get variation of 680 Volt! At a distance of pole such that diameter of belt would be say 100 miles we would have density $\frac{8000}{100}$ times and therefore the voltage 80 times greater than at equatorial

belt. Hence we may get variation of $340 \times 80 = 27200$ Volts. Taking capacity of about 1000 cm we could collect apparent energy $\frac{1}{2} \cdot \frac{1000}{9 \times 10^{11}} \cdot 27^2 \times 10^6 = \frac{4}{10}$ Watt approx. And with say 100000 per sec

$\omega = 6 \times 10^5$ about we would get $6 \times 10^5 \times \frac{4}{10} = 640000$ Watts* apparent energy, but this is impossi-

* I.e. 240000 Watts.

ble as the circuit could not draw from Earth except within a limited radius from ground connection.

Real energy generator. $\frac{\text{real on generator}}{\text{apparent on receiver}} \times 64 \times 10^4 = \frac{150 \times 750}{6666 \times 10^7} \times 640000 = \text{roughly } \frac{2}{100}$ Watts for 150 H.P. on generator.

Preceding results further considered

Data: Capacity of terminal 1000 cm.

Effective area = $\frac{\pi \times 12^2 \times 30}{6}$ square feet.

Volt $10^7 \omega = 6 \times 10^5$ (roughly), $\frac{\lambda}{2} = 1$ mile approx.

(This is only to get idea of effects at distance.)

Surface of equatorial belt $\pi \times 8000 \times 5300$ square feet

Taking at terminal roof of transmitter $\sigma = 10$ we have density on ground equatorial belt:

$$\sigma_1 = \frac{\pi \times 144 \times 30}{6 \times \pi \times 8000 \times 5300} \cdot 10 = \frac{72}{8000 \times 53}$$

With a similar roof terminal at receiving end we could get:

$$\frac{\pi \times 144 \times 30 \times 144 \times 6.5}{6} \times \frac{72}{8000 \times 53} \times \frac{1}{3 \times 10^9} \text{ Coulomb.}$$

With $\omega = 6 \times 10^5$ we have

$$\begin{aligned} &= \frac{\pi \times 3 \times 6.5 \times 144 \times 144 \times 72 \times 6 \times 10^5}{6 \times 8000 \times 53 \times 3 \times 10^9} = \\ &= \frac{52.22 \times 20736 \times 72}{8000 \times 10^4 \times 159} = \frac{7798 \times 10^4}{10^7 \times 1272} = \frac{7798}{1272 \times 10^3} = \frac{6}{10^3}. \end{aligned}$$

This in amperes without resonating rise.

Roughly we shall have $I = \epsilon C \omega$

$$\frac{6}{10^3} = \epsilon \frac{1000}{9 \times 10^{11}} \cdot 6 \times 10^5 \quad \epsilon = 9 \text{ Volts.}$$

Energy would be: $\epsilon i = \frac{9 \times 6}{10^3} = \frac{54}{10^3}$ Watts.

Energy per cm square with 200 H.P. at generator would be roughly:

$$\begin{aligned} &\frac{54}{10^3 \times \pi \times 144 \times 30 \times 144 \times 6.5} \text{ Watts per 10000 square meter} \\ &\frac{10000 \times 10000 \times 54}{10^4 \times 3 \times \pi \times 144 \times 144 \times 6.5} = \frac{54 \times 10^4}{9.42 \times 6.5 \times 144 \times 144} = \frac{540}{21 \times 61} \\ &= \frac{540}{1280} = \frac{54}{128} = \text{Say } \frac{1}{2} \text{ Watt (This can not be true).} \end{aligned}$$

Remark: Among newly found notes which Tesla wrote after he was in Colorado Springs, there are three documents that are missing in the published book "Nikola Tesla: Colorado Springs Notes 1899-1900", Nolit, Belgrade, 1976. Here we give some short comments on these documents.

Colorado Springs

August 4, 1899

Between August 2 and 14, 1899, Tesla considered a number of receiver arrangements with sensitive devices and involving condenser method of magnifying effects including "self-exciting" process. Some of these arrangements are patented in^{84, 85}. Recently some more insight into this type of receiver can be found in a published paper⁸⁶. There is no note dated August 4, 1899 in the "Colorado Springs Notes 1899-1900". In the newly found note Tesla describes "*Sensitive receiver for detecting feeble disturbances*", and mentions that it is based on a principle briefly described "*on a previous occasion which formed the subject of experiments about two years ago*" (1897). Tesla's work on detecting feeble signals is often mentioned in his notes and patents but without detailed explanations we do not know how applicable they were.

Colorado Springs

Sept. 5, 1899

In the "Colorado Springs Notes 1899-1900" dated September 5, 1899 one can find circuit connections and explanation of "coil vibration" measuring technique. There Tesla explained the way he measured inductance of "freshly wound experimental coil" with wires № 18 and № 20. The coil that is mentioned in the new document is an old coil wound with wires № 18 and № 22, and it is not clear why Tesla excluded it from the Notes.

Colorado Springs

Sept. 7, 1899

There seems that the newly found note does not contain any new results – the table is written somewhat different but the data are the same.

After returning from Colorado Springs and before moving to a new laboratory in Long Island Tesla wrote again notes – not regularly as in Colorado Springs. So far, in the Archive of the Nikola Tesla Museum in Belgrade only six-days notes are found from 1900, and somewhat more in the first half of 1901. As the notes are mainly written on memorandums of the Waldorf – Astoria hotel in New York, he wrote them either in New York or in Long Island when he was visiting future site of his Wardenclyffe laboratory. In June 1902, Tesla moved his laboratory operations from his Houston Street laboratory to Wardenclyffe.

New York

June 2, 1900

Like in his "Colorado Springs Notes 1899-1900", at the beginning of his research there (see notes of June 2, 1899, June 3, 1899 and June 4, 1899), Tesla begins his new notes with a review of interesting topics. In connection with insulating of conductors affected by cooling Tesla obtained patent⁸⁷ and in connection with the diminution of resistance another patent⁸⁸. There is no evidence that he used cooling in order to reduce the coil resistance.

New York

July 23, 1900

Here Tesla considers excitation in his "system of transmission through the Earth". In his attempts to obtain good contact with the ground he tried a possibility to use a conductive ball placed in the ground and surrounded by a conducting enclosure. In this way he obtained neutral point away from the imperfect ground. It is interesting to know that similar requirement about the length of wire "from ground to top" appears in his patent "Art of transmitting electrical energy through natural media", applied May 16, 1900, renewed June 17, 1902 and issued as US patent № 787,412, dated April 18, 1905. In that patent he also stated "that the planet behaves like a perfectly smooth or polished conductor of inappreciable resistance with capacity and self induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation".

The Waldorf Astoria

August 5, 1900

At this point it is not known why he considers heat transfer – obviously it is in connection with his list given on June 2, 1900 under headings: Heat supplied at rate computed; Cooling agents {gas, fluid liquid} and Special care when air is used. Some connections exist between considered questions and his patent "Method of insulating electrical conductors", applied June 15, 1900 and issued under US Pat. № 655,838, dated August 14, 1900.

New York

September 3, 1900 (dok.102)

These calculations are in connection with his interest for nature production of carbon dioxide and oxygen by the forest.

New York

November 24, 1900

565

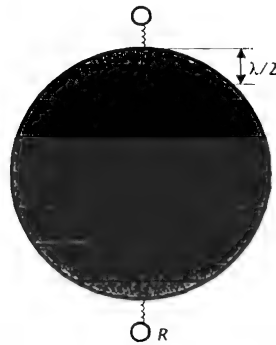
In order to get some indication as to the Earth capacitance and inductance Tesla considered Earth as a straight conductor of length 8000 miles and the mean diameter 4000 miles. This is a very crud model because the calculation of inductance is based on assumed straight conductor inductance and capacitance is calculated from the radius of the sphere in cm divided by 9×10^{11} to get it in farads (it is in fact obtained from the expression for the electrostatic capacitance of an isolated sphere in SI units: $C_{S_1} = 4\pi\epsilon_0 R$, where R is radius of the sphere, and ϵ_0 is the free space permittivity). The period Tesla calculated from Thomson's formula $T = 2\pi\sqrt{LC}$, as if we have an LC resonant circuit!

There is also a numerical error in calculation of the Earth vibration – it is 10 times higher and consequently the wavelength is 10 times shorter.

New York,

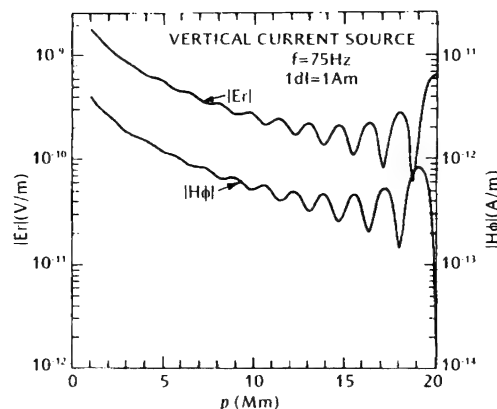
November 28, 1900 (dok.252)

Calculation performed is based on the electrostatic case, but with assumption that it can be applied as well for relatively low frequencies. Tesla assumes that if we have two spheres of surfaces S_1 and S_2 and charge them with $+q$ and $-q$, respectively, the ratio of sphere potentials is $\frac{p_1}{p_2} = \frac{S_2}{S_1}$. For isolated sphere its surface is proportional to the capacitance of the same so we can write $\left| \frac{p}{p} \right| = \frac{C}{c}$ (see picture)



Due to proximity effect this capacitance is changed and Tesla takes that in some way by saying that the isolated capacity is changing with the height! In his low frequency case he assumed that S_2 is the half-wavelength sector on the globe over which he assumes charge of the same polarity. The particular equator sector is cylindrical and its surface is given by $S_{2c} = \frac{\lambda}{2} \pi D$. The potential along this belt is, according to Tesla, $p_{2c} = \frac{2S_1}{\lambda \pi D} p_1$. As a next step he assumes that if resonance is used the voltage p_{2c} is multiplied by a factor Q . Energy per charge is assumed to be $W = \frac{1}{2} C_r (p_{2c} Q)^2$, where C_r is the capacitance of receiver. For one cycle of the source, received energy is $2W$ and the power received would be given by $P_r = 2Wf$.

Many objections as to the validity of Tesla's approach can be made, let we mention some: even the problem of two unequal size metallic spheres would require full correction for the proximity effect; expectations that the standing wave will be established are also very unlikely in the amount that would enable efficient electrical energy transmission; his model of transmission through the Earth axis is questionable etc.

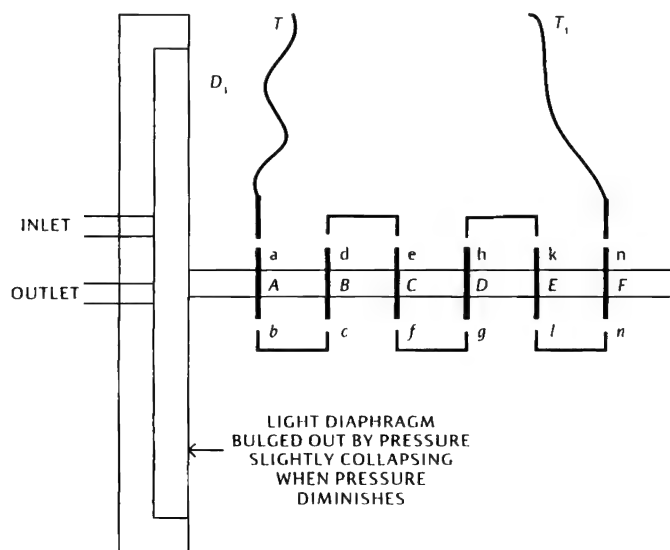


As an illustration, proving that Tesla had a premonition of unusual transmission phenomenon at very low frequencies, in the above graph we present the field distribution calculated over the Earth from a vertical line current (the source strength is $Idl = 1\text{Am}$) and the frequency 75 Hz.⁹³ This calculation is the principal field in the Earth-ionosphere waveguide radiated by a vertical electric current source. It is clear that a standing wave is detectable from about the equator region and it is most pronounced at the antipodal region.

New York

Nov. 28, 1900

In the "Colorado Springs Notes 1899-1900" on June 14, 1899 Tesla described similar arrangements "suitable for telephony at a distance without wires and for such purposes where it is necessary to effect control of a powerful apparatus by feeble impulses such as those produced by a human voice".



In this arrangement vibration of the diaphragm D_1 causes multiple arc disturbance of the current flow between T and T_1 which, in Tesla's opinion, is better than the similar control of a single arc. Controlling output power of a transmitter by air flow modulated by human voice acting on an arc Tesla tried to patent judging from the prepared diagrams found in the Archives of Nikola Tesla Museum in Belgrade and published in the "Colorado Springs Notes 1899-1900", Nolit, Belgrade, 1976.

Few months in 1901 Tesla continued to write notes preparing new equipment and further developing his theory of wireless energy transmission.

New York

January 24, 1901

Here we have insight into Tesla's approach to designing motor windings.

New York

January 29, 1901

This is continuation of notes from Nov. 24, 1900 regarding estimation of Earth's constants – capacitance and inductance. Now Tesla considers the Earth as a cylindrical conductor, assumes that the length of conductor is the same as the diameter of the Earth, and calculates radius of this conductor to have the same capacitance as the Earth sphere.

According to Jordan⁸⁹, if we equalize capacitance of a sphere of diameter D and capacitance of a cylindrical conductor of length D and radius r_1 , after simple calculation we obtain a nonlinear equation

$$x - 1 + a \sinh(x^{-1}) - \sqrt{1 + x^2} = 0,$$

where $x = \frac{r_1}{D}$. Solving the above equation numerically we get $x=0.382909$, and for $D=3957$ miles, we get $r_1 = 3030$ miles, not much different from 2910 miles obtained by Tesla.

On Nov. 24, 1900 Tesla calculated inductance by assuming mean Earth radius $D/2 = 4000$ miles! Then he obtained for inductance of Earth 1.63 H. With the new equivalent cylinder he obtained 2.4 H.

It should be borne in mind that Tesla had been developing his "wireless transmission of energy" on many questionable assumptions, relaying too much on intuition, and on some measurements on July 3, 1899 when he was convinced that he was observing stationary waves caused by a storm followed by a numerous electrical discharges.

New York

February 2, 1901

Modern theory of lossless transmission line, which Tesla considers in this case, is based on the solution of two equations

$$U_l = U_t \cos \beta l + j Z_c I_t \sin \beta l$$

$$I_l = I_t \cos \beta l + j \frac{U_t}{Z_c} \sin \beta l$$

where U_t and I_t are terminating voltage and current at the end of line, and U_l and I_l are the voltage and current at the distance l from the end of line.

The line phase constant is $\beta = \omega \sqrt{L_u C_u} = \omega \frac{\sqrt{\epsilon_r}}{3 \cdot 10^8}$, and the characteristic impedance $Z_c = \sqrt{\frac{L_u}{C_u}} = \frac{138}{\sqrt{\epsilon_r}} \log \frac{R}{r}$. In the latter two expressions L_u and C_u are inductance and capacitance per unit length of line, respectively. If the line is open $I_t = 0$, then the open line voltage is $U_t = U_l / \cos \beta l$ and the input impedance is $Z_l = j Z_c \tan \beta l$. In Tesla's notation, the condition for "transmitting energy under conditions exceptionally favorable" is achieved under the condition $p = \frac{1}{\sqrt{LC}} = \frac{1}{l \sqrt{L_u C_u}}$. At this particu-

lar frequency the line phase constant is $\beta_{\omega=p} = \frac{1}{l}$, and $U_i = U_l / \cos(\beta_{\omega=p} l)$. In SI system of unit, distance at which this condition is fulfilled is obtained from equation

$$l_p = \frac{3 \cdot 10^8}{p \cdot \sqrt{\epsilon_r}} = \frac{2 \cdot 10^8}{6 \cdot 10^4} = 333 \text{ m.}$$

Tesla did not consider transmission line equations although they were known long time (William Thomson 1855, Gustav Kirchoff, 1857, Oliver Heaviside, Michael Pupin, and others). He followed his own guesses, probably thinking that at a particular frequency when a series inductance and shunt capacitance (which is equivalent circuit of a section of the line) counteract each other we have a favorable condition for transmission.

New York

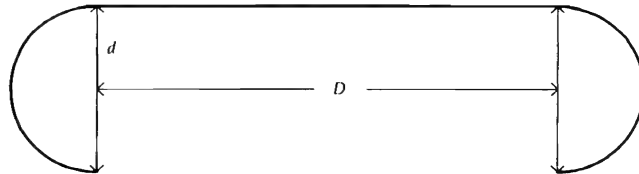
February 14, 1901

Considering operation of his coupled resonant circuits Tesla tried to investigate the effect of different resonant frequency of the two coupled circuits. The reason for this is probably his observance that there are intermittent sparks from the secondary terminal which reduce primary inductance from L_p to $L_p(1-k^2)$, if secondary is short circuited and $k = M^2/(L_p L_s)$ is the coupling coefficient. There are many variables in coupled circuit system: frequencies of the free vibration of primary and secondary coils, coupling between coils and losses. Besides circuit parameters the spark that discharges primary capacitance considerably affects the operation of the system. In the "Colorado Springs Notes 1899-1900" in Appendix I, some results of the coupled circuit theory are presented. If coupling is relatively strong, very fast transmission of energy from the primary circuit is possible: in the case of equal frequencies of the two circuits, this time is determined by a simple relation $\Delta\tau = \frac{1}{2(f_a - f_b)}$, where $f_a = \frac{f_0}{\sqrt{1-k}}$; $f_b = \frac{f_0}{\sqrt{1+k}}$. Obviously, the stronger coupling the energy transfer is faster, but in the period of $\Delta\tau$ the system generate two frequencies and if the spark is after $\Delta\tau$ extinguished, the secondary continue to oscillate at its own resonant frequency.

New York

March 1, 1901

Here Tesla specifies new capacitive terminal – flat metal roof without sharp edges. Neglecting some small numerical error he calculates inductance that would with the roof capacitance be in series resonance at two frequencies: 50 kHz and 125 Hz. In the first case inductance is no problem but in the second case he has to consider using iron core inductance.



Calculation of the received power at a point along the equatorial belt is the same as already explained on Nov.28, 1900 notes. As he assumes belt 1 mile wide, according to his theory the belt should be $\lambda/2$ or $186000/(2 \cdot 50000) = 1.86$ miles, his calculations are for $f=50$ kHz, and magnifying factor 10000. He did not calculate received signal under similar conditions for frequency of 125 Hz. The

latter received signal would be much smaller because of greater belt size (400 times), smaller magnification factor (0.0016 times) and lower frequency (400 times). We estimate that the signal would be $4 \cdot 10^{-14}$ times smaller!

New York

March 24, 1901

These are investigations into some of his "preferred arrangements" for tuning primary and secondary. In the first arrangement he uses a variable part of the secondary inductance as a primary circuit inductance. In arrangements a) and b) he fixes the coupling point and adjusts primary reactance by adding a variable inductance or variable capacitance, respectively. The last arrangement is the most complex – it has three resonant circuits and he expects better results to be attainable with it.

New York

April 1, 1901

These are consideration based on old notes. Here he applies his theory again as on Nov. 28, 1900 and March 1, 1901 but extends it to find power at the pole. Again he selects frequency 50 kHz, and a magnifying factor 10000, initial charge one million volts. For the first time he derives power that could be received at the pole – according to his model the received power is 53 W! He considers this result "Great". He did not explain how he got the density at the pole 4000/3 times greater.

The same day he discusses arrangements when the apparatus is used alternatively as transmitter and receiver. He uses the same high frequency transformer (Tesla coil) both in transmitting and receiving arrangements. The differences between the two arrangements are in the position of the break. When an ordinary arc break is used it can stay in the receiver disposition because it is open circuit for the small receiving signal.

New York

April 15, 1901

This is further development of consideration regarding elevated conducting terminal. Starting from parallel plate disk condenser, and neglecting the edge effect he calculate capacitance from classical formula $C = \epsilon_r \frac{S}{4\pi b}$ in CGS system, where the disk area is $S = \pi r^2$, b is the disks separation and ϵ_r is relative permittivity of the dielectric between plates. All calculations he made in order to clarify some design point in making elevated terminal.

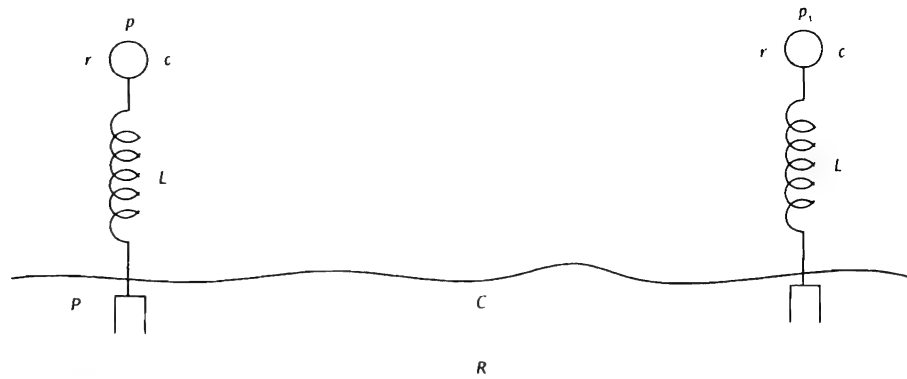
Under the same date, a note was found in another folder that deals with transmitter design. In it Tesla gives calculation of inductance coil to be placed in series with the output of the main transformer in order to prevent short-circuiting by the break.

New York

April 28, 1901

Here is continuation of consideration of terminal capacitance vs. actual size of terminal and available charge. With smaller capacitance and increased pressure he expect to have the same electrical movement in view of the relation $p'C' = p''C''$, but when considering the change of energy he finds

that their ratio is $W'/W'' = C''/C'$ which means that decrease in capacitance require proportional increase of energy supplied for the same electrical movement.



Next, he considers signaling through the Earth by his model of low frequency propagation based on initial relation of equal charge supplied to an elevated terminal and the earth region. In each period he assumes that the total variation of charge is $2q$ (neglecting time variation and taking rather "step" functional periodic signal). Here he gives some more details about his theory by stating that the electric densities on the sphere and on Earth surface are q/s and Q/S , s and S being the surfaces of the sphere and of Earth, respectively. The total variation of density during one whole cycle on surface of Earth he found to be $2q/S$, and states that this requires slow variation of charge of the order 4 c/s.

To realize a source of frequency 4 c/s he assumes to use a two-pole machine rotating $240/60=4$ rev/sec. From energy per cycle of this machine (not Watts but Joules) and assumed terminal capacitance he finds pressure (voltage on the sphere) 288000 Volts while it should be 10 times higher.

Consequently, all other calculations relaying on this value have to be changed.

For improving sensitivity of the receiver here Tesla mentions his patent on "integrate and damp receiver"⁹⁰. In spite of the numerical error Tesla concludes that he expects "That signals can be transmitted to any distance by my system is therefore perfectly sure."

Next Tesla increased frequency to 60 c/s. This frequency corresponds to that of the generator ordered for new laboratory. Belt of alternating high and low density in this case is 2665000 miles. Compared with the previous case, the operating frequency for the same other conditions will be greater as the ratio of the whole earth surface and the surface of the equatorial belt in the second case which is $2D/\lambda = 4.76 \times \pi$. Here Tesla assumes higher magnification factor of $2\pi \cdot 60$, and increased energy 15^2 times. Overall improvements he estimates to be considerable. Tesla was aware that his approach to transmission "without radiation" relies on the static charge redistribution and this can work only for very low frequency.

If higher frequency is used, Tesla's theory predicts considerably increase of the received signal. In his model improvements are due to increasing frequency leading to a smaller belt area which results in higher charge density, and higher performance factor due to resonance.

Just to see what would happen if much higher frequency of 100 kHz is used Tesla calculated improvements and discusses modulation rate if digital signals are used.

Following idea of signaling Tesla described a receiver with a wire heated by the incoming signal and by its elongation affects a microphone contact in an induction coil primary.

New York

May 1, 1901

Now Tesla assumes power of five million horse power and calculates the voltage to which the capacitance of an elevated terminal must be charged at the rate 40 per sec. From this voltage and the ratio of elevated terminal capacitance and capacitance of Earth he finds potential on Earth per half cycle from the equation $p_A C_A = p_E C_E$, where index A refers to elevated terminal and E to Earth (p potential and C capacitance). At such high power of 3750 MW, received power with magnification by resonance of 10 is 8000 W, so only approximately $2 \cdot 10^{-6}$ part of the transmitted power is received. However, Tesla seems to be impressed by this result and concludes that even transmission to other planet is possible!

New York

May 4, 1901

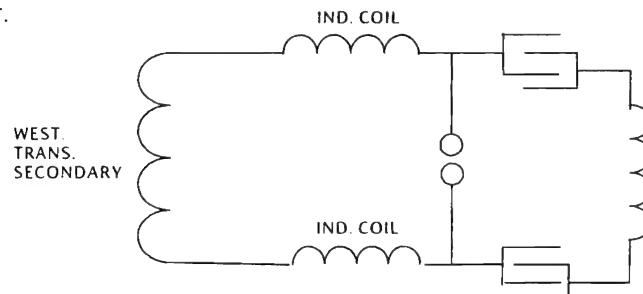
A short note about readjustment of laboratory apparatus mentions three coils: one central in the laboratory and another for "physiological effects" and third for lighting tubes in hand.

Note explains observation of unexpected coupling behavior of two loops: one placed in the laboratory and other movable with small incandescent lamp as indicator of received power.

New York

May 10, 1901

In this note we can see the whole design procedure of induction coils placed between the main Westinghouse transformer and Tesla's spark oscillator. These induction coils prevent short-circuiting of the main transformer when sparks initiate discharging of the condensers through the primary of high frequency transformer.



The coils are selected for known frequency of makes and breaks and condensers in the oscillator circuit. The condensers are charged periodically and selection of inductance L is such that we have a series resonance in the charging series resonant circuit of inductance $2L$ and capacitance $C/2$.

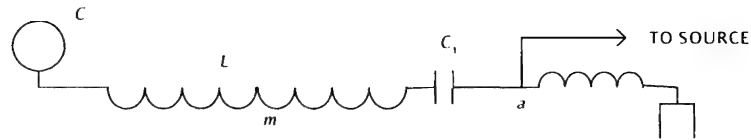
New York

May 19, 1901

Several pages of the notes under this date describe various things. The first page deals with the *grounding* of the transmitter secondary. The lower terminal of the secondary can be connected directly to the grounded plate or through a capacitance. In view of relatively low frequency with which he operated his apparatus, he had poor ground connection even with few square meters metal plate buried in the ground. The reason for different behavior of the three cases may be unequal loading of the secondary circuit.

Insulation of terminal is another problem to Tesla. Here he sketched two possible solutions: first in which metallic roof has to be isolated and feeding is from multiple secondary; with the second arrangement metallic supports of the roof terminal are acceptable and they form a kind of loop coupled with a number of primary loops as shown in picture.

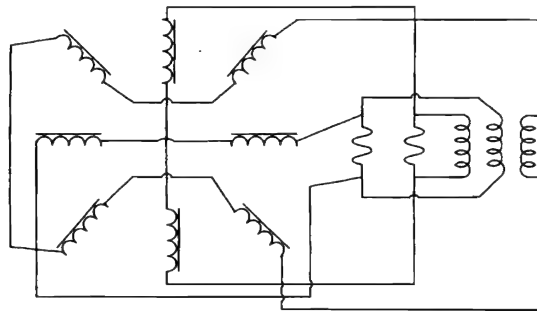
Determination of capacities is based on resonance method – it is continuation of measuring technique practiced from October 21, 1899 and for several other days. Here he determines the voltage distribution along the coil L and from the size of spark locates a neutral point m by minimum spark.



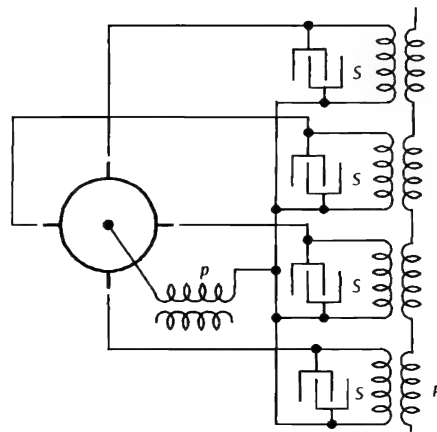
Under a subtitle "From old note" he considers two different questions:

Message transmission to a planet Mars by making rhythmical variation of the potential of Earth through a powerful oscillator. It seems that in this case he does not consider radiation but again electrostatic influence at a huge distance between the Earth and Mars!

Motor with great torque and no dead point is interesting in that it operates from a two-phase alternating current system but with suitable transformers it is converted into a four phase motor. To Tesla, this is better than a three phase motor and the similar technique he thinks it can be applied to three-phase motors.



New York
May 24, 1901

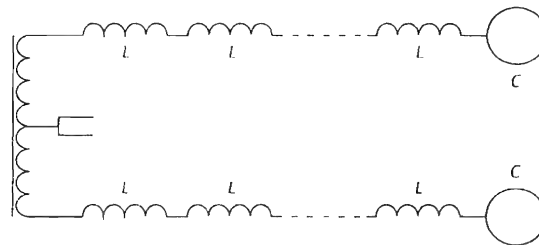


Here Tesla again reconsiders arrangements with several condensers charged in sequence into the system shown in Figure. With this arrangement he can charge four condensers from one mains transformer and reduce noise coming from the sparks. He claims that in this way the loss is reduced as through each spark gap only $\frac{1}{4}$ of the currents passes as compared to full current when only one spark gap is used.

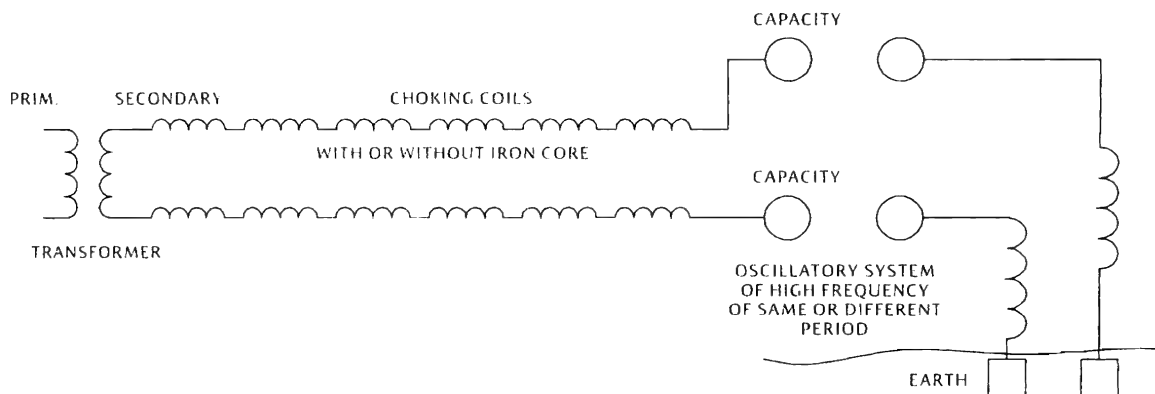
New York

May 26, 1901

On May 10, 1901 Tesla investigated the use of two simple circuits consisting of the series inductances (chock coils) and large capacities on each terminal end. The driving source of these circuits is high tension secondary of the mains transformer with center tap.



Tesla assumes that if the central point of the mains transformer is connected to ground, there will be two series resonant circuits which have to satisfy equation $\omega_r = 1/\sqrt{nLC}$ in order to get maximum voltage on capacity C . For work with 130 Hz source he estimates that 444 coils are needed and that is not feasible. He then assumes 10 times higher terminal capacitance and finer wire in making chock coils and for the same frequency he reduces number of coils to about 11, or 6 coils in each leg. Voltage on the capacitance he calculates from $e \frac{\omega_r L_r}{R_r}$ as if the internal resistance of the mains transformer is zero. His conclusion was that this can work and be used in telegraphy without wires. He provides a scheme



where initial high voltage is used to drive another two circuits which may be of the same or different period and produce current in the Earth as "in the two systems in accordance with my method".

New York

May 29, 1901

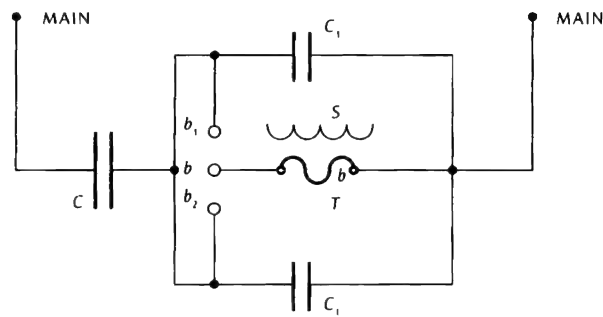
Notes from October 1900 are not among these notes. According to present note he considered modulation format needed in message transmission. So far Tesla experimented with a number of ways of controlling oscillators, of which the first two are interpreted in a modern way as a) Intensity modula-

tion, b) and c) Frequency or phase modulation. The case d) has one fixed and other variable frequency and is a combination of intensity and angle modulation. It seems that e) to h) belong to receiver design as well as m) and n). Generally, in order to have strong effect on the carrier by applying a small power of message signal, Tesla looked for special techniques to achieve this.

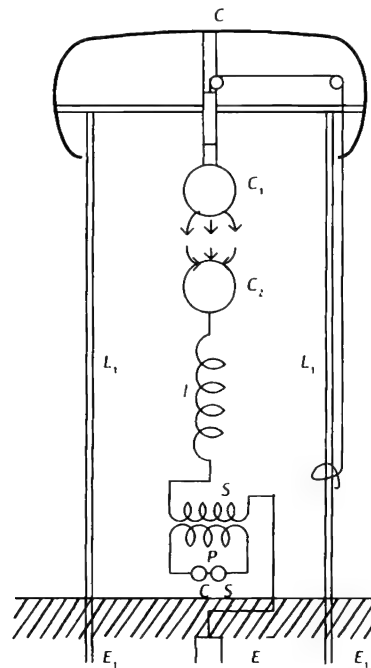
At the time when in the world only pulse modulation had been developing, Tesla already had experience with amplitude, angle and pulse modulation techniques.

Following "old note" Tesla presented "an excellent arrangement in signaling without wires suitable for both transmitter and receiver". In that arrangement he expected to use two circuits tightly coupled and when one circuit produce frequency slightly different from the other, the great intensity variation of transmitted signal is achieved. If one signal is $u_1(t) = U \cos(\omega t)$ and the other with slightly different frequency but the same amplitude $u_2(t) = U \cos((\omega + 2\delta\omega)t)$, the signal emitted would be $u_{1+2}(t) = 2 \cdot U \cdot \cos(\delta\omega \cdot t) \cos[(\omega + \delta\omega)t]$.

Hence the signal is amplitude modulated and even for small $\delta\omega/\omega$ the effect of frequency shift is significant.



Another "old notes of experiments" analyze oscillatory arrangements with a series condenser C that prevents short-circuit effect of the break. With no connections bb_1 or bb_2 both condensers C_1 are



charged through C . When bb_1 is shorted by arc or break, condenser C_1 discharges into primary T and generates high frequency current. Similarly when in the next moment bb_2 is shorted by arc or break

lower condenser C_2 discharges into the same primary T . Tesla experimented with similar arrangements by taking 24 condensers!

Still another "From old notes" deal with a terminal supported on conducting supports. Having in mind difficulties if an isolated terminal C is required, Tesla tries to avoid it by using another resonant circuit composed of c, CL_1L_1 . It is not stated whether the driving coil P is also a part of primary resonant circuit. Brief calculation of resonance for the considered roof supporting structure was made for 100 kHz signal. As this is much higher frequency than needed, Tesla concludes that there is not enough inductance to achieve low frequency resonance of c, CL_1L_1 system.

New York

May 30, 1901

In summarizing some previous calculation Tesla again uses unit *watt* for energy instead of *joule*. When multiplied by number of charges per second than it is the power. If energy per charge would be 1000 joules, and when considering 5000 charges per second in 1 second we would require energy of 5000000 joules/second, i.e. the required power is 5 MW! Considering charging and discharging he reduces this to 2.5 MW (he call Watt rate).

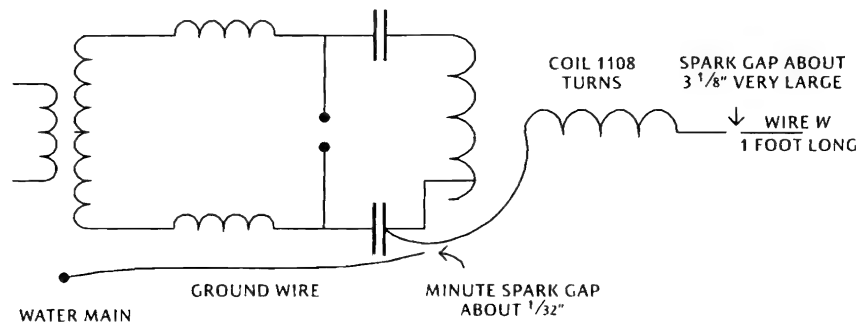
Further reduction of required power Tesla expect because of pulsed signaling which do not require continuous operation of the transmitter.

The same day Tesla changed the subject and discussed transmission through a wire print, pictures or images. Here he explains how a picture can be split into elements, each element projected on a miniature selenium cell and electrical signals from the cells be transmitted by his multi-frequency combination signals – all through a single wire without interference. At the receiving side the signals are separated and projected in the same order as on the transmitter side. This would be a kind of parallel transmission similar to the transmission of picture signals from the eye through a bundle of nerves to the brain. Tesla's system does not require a bundle of wires because he proposes multiple frequency signals that can be transmitted through a single wire without interference.

New York

June 1, 1901

The operating frequency of Tesla coil spark-gap oscillator is dependant on all circuit parameters. Any addition of wire or change in the position of coils, coupling or even sparking will change the frequency.



In this experiment Tesla tried to examine the effect of ground wire connected to water main on resonant circuit composed of two series capacitances and regulating coil (variable inductance). In this way it is difficult to exactly determine the effects but it confirms expectations that any addition of wire would change the operating frequency. By measuring the spark intensity Tesla determined the resonance and the difference is shown in different number of regulating coil.

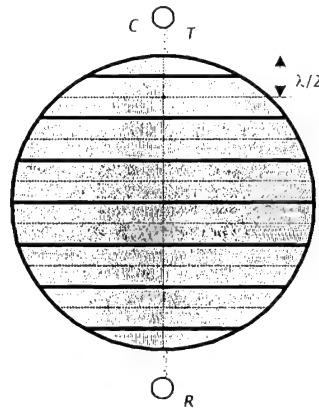
With the same arrangement but instead of coil with 1108 turns he connected large secondary spiral coil with one primary turn connected to a small lamp. The resonance measurements by lamp illumination Tesla prefer to determining resonance by the largest spark between the upper terminal of spiral coil and a piece of wire. With the same apparatus Tesla measured "extra coil" inductance.

Repeating measurements of spiral coil Tesla reduced inductance of the regulating coil until he obtained resonance with approximately $\frac{3}{4}\lambda$ length of wire in the spiral coil.

New York

June 2, 1901

The notes written on this date have 14 pages. Tesla's model of low frequency current distribution through the Earth from a transmitter of capacitance C is shown graphically with a standing wave: dashed lines are "zero" current, full thick lines are "peak" current lines. Standing waves and the conditions under which they can be formed are explained in his patent "Art of transmitting Electrical Energy through the natural mediums", applied May 16, 1900, renewed June 17, 1902 and issued on April 18, 1905⁴².



As already explained (see for example note of November 28, 1900) he assumes that standing waves can be established on the earth as graphically shown in the above Figure. Transmitter antenna is charging alternatively zone with positive and negative charge and this creates a progressive wave which after the reflection from the antipode returns and produces standing wave.

For the moment Tesla assumes no loss and uniform distribution of charge over the zones!

This time he selected high frequency (100 kHz) as the earlier investigations with frequencies 4 Hz (see note April 28, 1901) or 60 Hz did not give optimistic results. The reason why higher frequency would give better results can be seen from the following equation which we derived on the basis of his hypothesis (Tesla calls it "theory") for the power received at the equatorial zone:

$$P_{RE} = C_R f_T \left(\frac{2S_T}{\lambda_T \pi D} p_i Q_R \right)^2$$

where S_T is the area of elevated transmitting terminal, p_i is potential on S_T , C_R is the capacitance of receiving antenna, Q_T is the improvement factor of receiving system, D is diameter of the Earth, f_T is the operating frequency and λ_T is the wavelength. If we take $Q_R = 2\pi f_T \frac{L_R}{R_R}$, from the above equation we find that the received power is proportional to f_T^4 , providing all the parameters are the same and independent of frequency.

In his notes Tesla raised a question of charge and power transfer by his system. If all charge is available at some zone, he asked whether by increasing capacitance of antenna we can collect all the

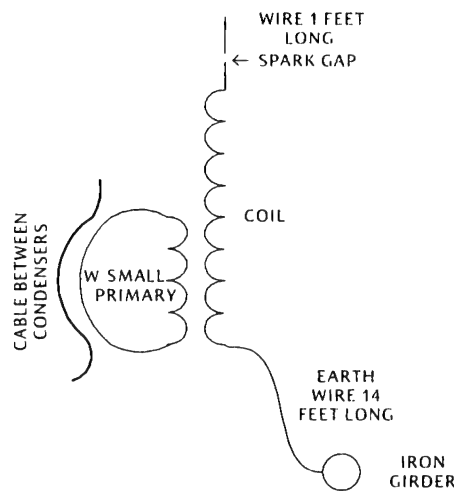
charge from the zone. Then if we collect all the charge will it enable full power transfer? To collect more charge Tesla assumed to use many wires at the polar cup arranged in concentric circles.

As some kind of conclusion at the end Tesla stated that his "estimates show that high frequency currents are imperative to employ".

New York

June 4, 1901

After a long discussion in connection with "Transmission of electrical energy by conduction through Earth" on June 2, 1901, Tesla returned to experiments and measurements of inductances. First he measured self-resonance of a spiral coil and then inductances of several new coils.



The measuring technique and equipments are as used on June 1, 1901. This time, instead of direct connection of the coil to a terminal of condenser (see June 1, 1901), loose coupling is made using a primary (of spiral coil) or auxiliary few turns small primary (for other coils) connected to wire *w* coupled to a cable connecting the two condensers in the oscillator circuit as shown in the figure.

New York

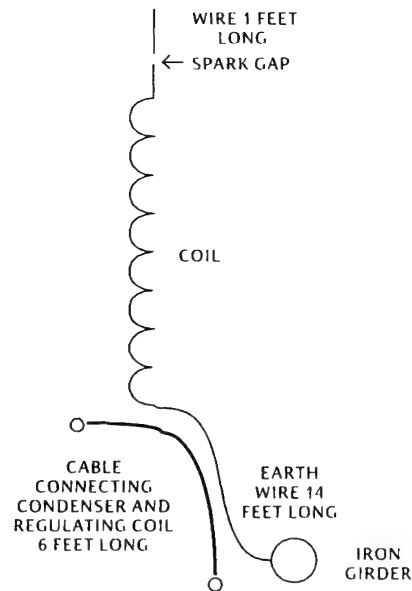
June 5, 1901

Measurements of the self-resonance of coils (or "freely vibrating circuit") are delicate in view of influence of coupling with the oscillator. As the coupling must be small, Tesla modified the previous circuit (see June 4, 1901) so that the induced signal comes from the oscillator through the ground cable 14 feet long which was passing near the 6 feet long cable connecting two condensers in the oscillator. In this way he obtained enough coupling which again, like many times before, he judges as acceptable by the size of the spark at resonance between the upper terminal of coil and a piece of wire 1 foot long.

In the presence of another coil – whether it was connected to the common ground wire or not - he detected influence and found, as could be expected, that this is a disturbing factor.

Throughout the "Colorado Springs Notes 1899-1900", in calculating inductance of coils wound on long cylinder, Tesla used formula valid for infinitely long cylindrical coil. On October 26, 1899 in "Comments and Remarks" we presented Russel's⁵⁷ formula with correcting terms for shorter coils. Tesla also did not take into account that his formula does not take into account frequency dependence of measured inductance caused by self-capacitance of coil. In fact, he was fully aware of the coil capaci-

tance and measured it from the knowledge of the free vibration of coil and calculated inductance, or measured inductance at low frequency.



New York

June 8, 1901

It is not quite clear why Tesla made so many measurements under various conditions with four coils described on June 4, 1901. He recorded 22 experiments investigating intensity of excitation by observing a small lamp connected to an auxiliary few turns primary wound around tested coils.

The same day he again returned to calculations of transmission of energy through Earth at frequency of 60 Hz. He was in the process of construction of an alternating current dynamo operating at 60 Hz. He compared results with those obtained on June 2, 1901 for a similar arrangement but operating at 100 kHz. First he calculates the voltage to which the capacitance C of transmitter has to be charged $2 \cdot f_G$ times per second so that all energy from the generator is to be used:

$$P = \sqrt{\frac{P_G}{C f_G}}$$

where P_G is the available power and f_G is the operating frequency of the generator. Subsequent calculation has not been supported by full explanation because we know that there are differences in parameters for the two considered frequencies.

New York

June 9, 1901

This is again continuation of measurements with the apparatus used on June 4 and 5, 1901.

New York

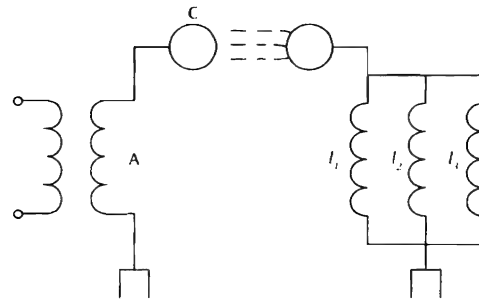
June 11, 1901

Here Tesla collects data about various earlier made coils and six new coils. He presents results of measurements in the number of turns of regulating coil and number of jars in the capacity bank.

New York

June 13, 1901

It is known that Tesla had two patents on System of Signaling and Method of Signaling³⁸, in which he used transmitter generating two frequencies aimed at reducing interference and improving individualization (protection) of transmitted messages. Here he refers to some experiments in which he



worked with seven coils excited through spark discharge into a complex transmitter. Such system would generate complex signal. Still better he considers separating resonant coils and feeding then successively one after the other.

New York

June 14, 1901

Preparing for future experiments Tesla continued to measure inductances of auxiliary loop coil and coils made for ascertaining vibration of large laboratory apparatus.

New York

June 15, 1901

Here Tesla experimented with a coil suspended in air and then grounded on one side. The first resonance of a coil free on both ends is almost twice that when the same coil is grounded on one side. By careful measurements Tesla found that grounded coil have resonance somewhat higher than expected and he explains that it was due to the internal coil capacity which has different role in the two coil arrangements. He recommends grounded coil as a better combination, less affected by external influences.

New York

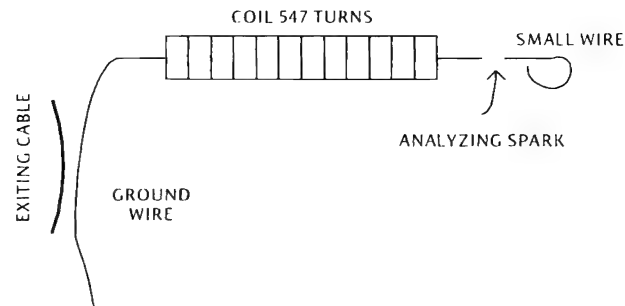
June 24, 1901

This note is interesting as it shows how Tesla operated vacuum tubes – probably for illumination. He designed series coils – current limiter – which are necessary for this type of tubes when connected to the mains.

New York

June 27, 1901

Using the same arrangements as on June 5, 1901 Tesla made measurements of new coils. First he measured one coil and then a series connection of two identical coils. With two coils inductance was



doubled but because resonant frequency is halved the quality factor of two coils in series is halved! The analyzing spark, which is indication of excitation level, dropped in the second measurements and Tesla explained why this happens.

New York

July 6, 1901

Here Tesla investigated mutual action of several identical coils connected in various ways. In the first experiment he connected to the ground two coils with perpendicular axes to minimize coupling. One coil is alone and the other had two additional coils connected in series, but again with perpendicular axes to minimize coupling. This is the test of single coil resonance vs. three coils in resonance. The resonances were indicated by small lamps as indicated on the figures. The second experiment is with one coil alone and two coils in series in the second branch. This is the test of single coil resonance vs. two coils in resonance.

New York

July 7, 1901

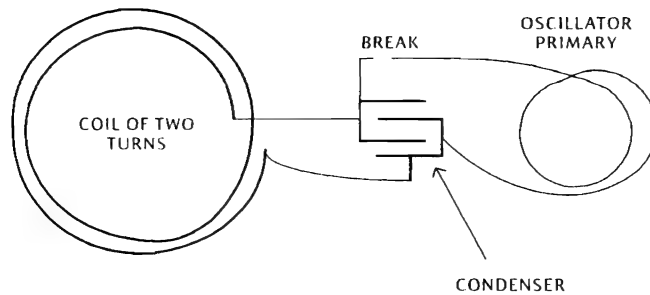
Here Tesla considers construction of a circuit for controlling model boat built more than three years ago. In the boat he put resonant circuit made of three turns coil and a condenser. The operating frequency seems to be about 120 kHz. He wanted to control the boat in the laboratory by induction from a large cable.

New York

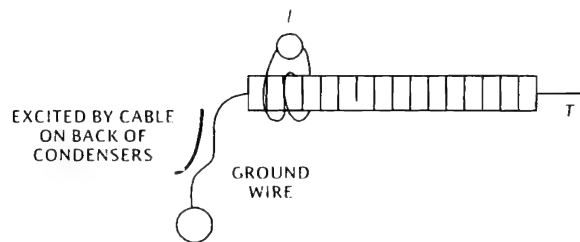
July 8, 1901

Frequency of small oscillator used for running vacuum tubes in laboratory operates around 24 kHz. To test its frequency, signal from an external oscillator is coupled through "coil of two turns", and "break" is bridged by a wire. Frequency of the external oscillator is varied until resonance of small oscillator is detected by a small lamp included in a secondary winding of few turns.

With the arrangements as on June 27, 1901 Tesla again measured free vibration of coil with 547 turns by observing maximum lighting of the lamp *l*. In numerous experiments with added capacitances on the terminal T, for constant excitation by the cable on the back of condensers, he found that the lamp *l* lighted always stronger with no capacitance attached.



Examining excitation through the ground wire Tesla inserted small air-core transformer with the lamp I_1 and observed variation of its lighting under various conditions. It is interesting that he measured illumination when connecting several identical coils in parallel as this is in connection with



his multi-feed transmitter (see Notes May 19, 1901). He found that current through the ground wire increase in proportion to the number of parallel connected identical coils. The arrangement with several coils in parallel is mentioned earlier in connection with "distributed" receivers for collecting more electrical charge (see Notes June 2, 1901).

New York

July 9, 1901

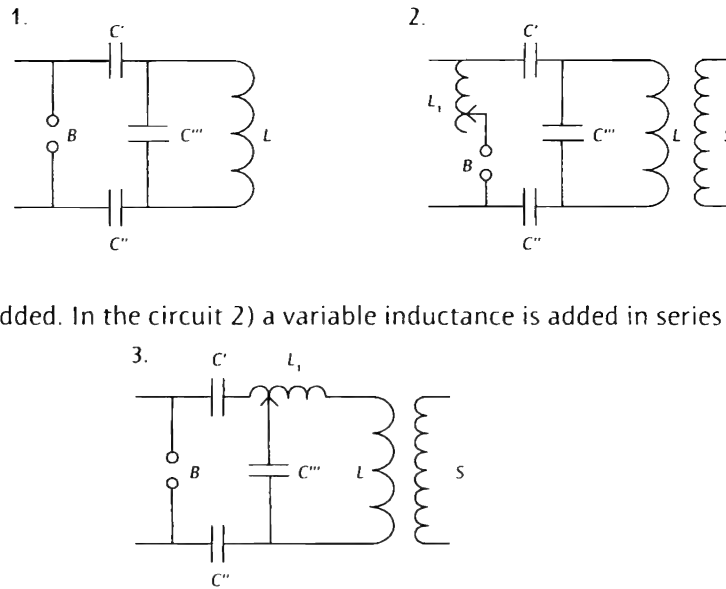
With the same basic arrangement Tesla continued measurements as on the previous day but in the ground wire he introduced a parallel plate condenser, then that condenser and a coil. It seems that Tesla made these experiments in order to learn more about various combinations of multiple coils connections.

New York

July 13, 1901

It is not clear why Tesla suspected that more energy is consumed on left side of condensers than on the right side *"when one side includes spark gap and the other has none"*. In the typical spark oscillator there is no capacitor C in the primary of "Tesla coil". The question whether the currents passing through points x and y are identical is difficult to resolve particularly in view of technique and method used to measure these currents. Without final conclusion Tesla put a note that "A delicate test is to be applied".

Continuing some earlier work ("From old notes") Tesla developed several circuits with adding a condenser C''' in his standard "Tesla coil" arrangement. With the circuit 1)

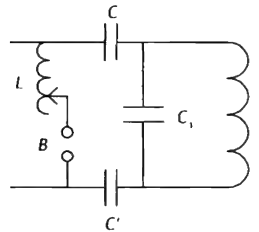


only condenser is added. In the circuit 2) a variable inductance is added in series with

the break, while in 3) similar inductance is added in series with $C'L_1L$. Since Tesla did not give any calculation here, his explanations of circuits operation are basically reduced to requirement that all resonant circuits be tuned to the same frequency. In the case 2) the three circuits seems to be: $C'L_1C''$, LC'' and secondary S. He does not say anything about coupling between L and S.

New York

July 15, 1901

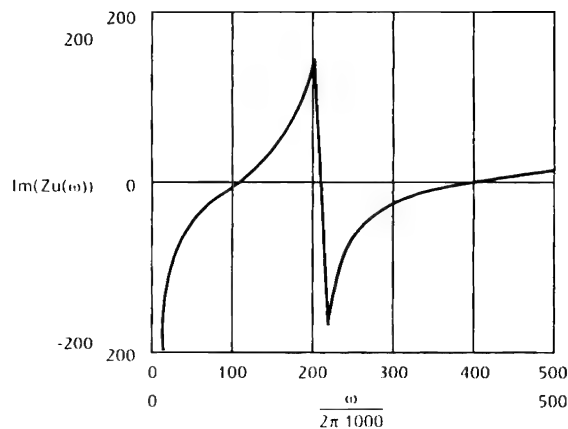


This is arrangement similar to 2) shown on July 13, 1901 but this time with different letters describing components and without secondary S. The two resonant circuits $C'BLC$ and C_1I he select with the same resonance so that we have $C_1I = L \frac{C}{2} = \frac{1}{\omega_r^2}$, since he assumes $C'=C$. With parameters that he selected and calculated in his notes, the resonant frequency was 207.9 kHz, not far from his estimation 200000 p.s. The impedance of the system with reference to spark-gap B is

$$Z_u(\omega) = R + j \left(\omega L - \frac{2}{\omega C} \right) + \frac{r + j\omega l}{1 - \omega^2 l C_1 + jr\omega C_1}$$

where we have taken that inductance L have resistance R and inductance I have resistance r.

Imaginary part of impedance $Z_u(\omega)$ has two zeroes and one pole close to calculated resonant frequency, and the frequency where Tesla expected that this system works. Full analysis would require solution of differential equations with initial conditions.



In various circuits Tesla often used relatively long connecting wires and in order to have “more accurate” results he included in calculations capacitances of wires when they are vertical or horizontal at known height above the ground. These considerations are in connection with designing of the future plant at Long Island.

New York

July 20, 1901

This circuit has the same elements as the circuit given on July 15, 1901, but here one condenser is placed in series with the inductance L . This inductance is made by two turn's cable wound on a square frame.

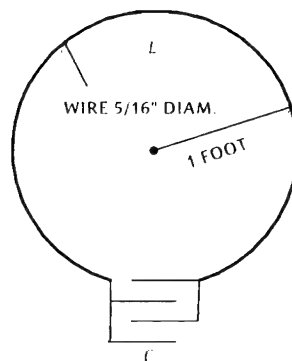
The same test circuit he used to measure coil intended for exciting large vacuum tubes and a large spiral coil.

The same day he returned to “old notes” and the stationary waves in connection with light houses, navigation, direction finding, distance etc. These stationary waves he proposes to obtain from two transmitters at various location and of definite frequency. It is interesting that he thinks that distance can be measured by determining the signal level! He thinks that even height can be estimated from standing waves.

Although in an elementary stage of idea development, this shows how Tesla's mind traced future navigation system to be used both at land, sea and in air.

New York

July 22, 1901



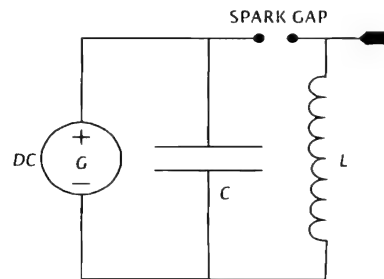
This is continuation of measurements of coils including reactance of the connecting wires with standard resonance method. The instrument for determining vibration of high frequency oscillators – called now the wave meter -Tesla made with condenser and a loop of 2 feet diameter.

This “wave meter” is similar to the one that was first used by Hertz in his famous experiments with electromagnetic waves, with the difference that C was at the same time a variable capacitance and a miniature spark gap for determining the moment of LC circuit resonance.

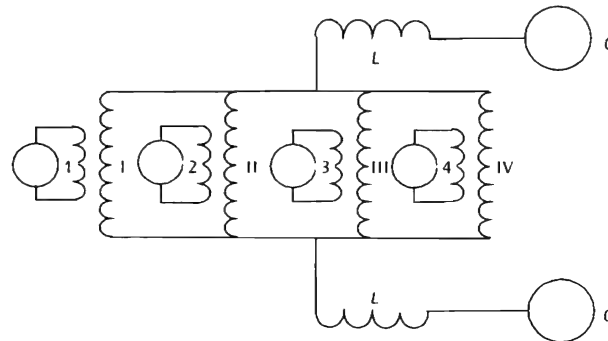
New York

July 30, 1901

Again starting “From old notes” Tesla continued investigations of high frequency oscillator in order to eliminate disturbing effects in wireless telephony caused by arcs or makes and breaks. In addition to enabling high frequency generation, arcs or makes and breaks induce unwanted audible modulation, much more with alternating current sources than with the direct current sources. He experimented with several arrangements considerable improved over the old ones. In addition to using high voltage direct currents source he required that the free vibration of LC system (see scheme 1) in July 30, 1901 Notes, or figure below) is in resonance with “makes and breaks”.



In another set of experiments Tesla combined several circuits with simple LC circuits as shown on the previous figure. It seems that all these experiments are directed towards producing highest power using parallel connection of smaller arrangements.



Another “From old notes” deals with some ideas in connection with wireless telegraphy. It is in connection with discussion of multi-driving system which can produce complex signals and which can be detected in multi-action receiver. Such signals, Tesla said, can be used for direct transmission of printed messages – the technique known today as “teleprinting”.

New York

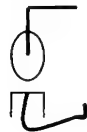
August 3, 1901

Here Tesla considers again his model of wireless energy transmission and possible effects on antenna structure. His calculation of available transmitter energy is correct but that energy must be taken away in some way, either by radiation or by dissipation in the ground or environment. As his antennas are small compared to the wavelength, radiation resistance is very small, hence radiation is negligible (that is what Tesla wanted!); ground resistance is another element where power can be dissipated. In Tesla's model he assumes that instead of radiation there will be a current wave carrying the energy away from the capacitive transmitter. Modern science does not recognize such waves without electromagnetic wave presence, recognize existence of standing waves around the antipode region if extremely low frequency radiation is used and accept the Earth resonance phenomena. However, all these does not look promising that even with the use of extremely high voltages and short "umbrella" antennas transmission of "large amount of energy" is possible⁹¹.

New York

August 19, 1901

This is one day when Tesla used some old notes and left his imagination work freely! Jumping from



theme to theme, some of them connected with break device with drops of water (see figure), other with the "use of singing flame in connection with telephone for magnifying voice". The latter is most likely in connection with the work of Duddell⁹² which was published in 1901.

New York

August 26, 1901

This is consideration in connection with elevated capacity which must stand high voltage and because of that it has to be made with high curvature radius surfaces. In order to estimate capacity of this roof he calculated surface as composed of calotte and curved tore. Guessing elevated roof capacitance of $C=20000$ cm (or 22222 pF), and assuming to operate at 100 kHz, or 50 kHz he calculated required series inductance with which the roof capacitance would be in resonance. With assumed charge of the condenser C to voltage V , n times per second he calculated energy per second, in fact power, from

$$P = \frac{1}{2} CV^2 \cdot n$$

With assumed $V=40000$ volts, $n=240$ per sec, and $C=250$ nF, (this is not the capacitance of the roof calculated above) $P=48$ kW or 64 H.P.

New York

August 28, 1901

In the note relative to wireless transmission of energy through Earth Tesla again repeated his conviction that all energy of transmitter, if the radiation is negligible, can be recovered at the Earth surface. He calculates energy per area, per second, from equation: $\frac{P_T}{S_E}$, assuming here that all the energy is uniformly distributed over the entire Earth surface. At this moment he does not speak about "zones" and distribution of charge if frequency is taken into account. Another curious calculation is the number of receiver of selected size that would "consume" all energy from equation $\frac{P_T}{S_E} S_R$, where S_R is the receiving area. By assuming that all the energy per second (P_T) can be delivered in much shorter time than second, he talks, in fact, about peak power in the shorter than the second interval.

New York

September 3, 1901

In general consideration relative to wireless transmission of energy, unusual to his previous approaches, Tesla presents his formulae in general terms. The final formula about the ratio of charge densities has been formulated and used earlier.

New York

September 8, 1901

For "World telegraphy" antenna system here Tesla gives a set of data needed for the construction of the structure. Top capacitance of the antenna (roof in Tesla's notation) he selected with rounded shapes (calotte and toroidal surface) as he expected to apply high voltages to it. After calculating capacitance he calculates inductance for selected operating frequency.

Other steps in calculations are repetition of the previous considerations and finally he takes into account the magnification factor and finishes up with the transmitter feeding current of enormous value.

New York

September 18, 1901

Tesla considered design of several towers discussed before, and this time he is presenting a smaller tower of cheap construction. After selecting construction he calculates its capacitance. Here he uses σ for the charge density (he calls it only "density"), multiply it by the surface and obtain charge – expressing here for the first time in Coulombs! Then from

$$\text{energy} = \text{capacitance} \cdot \text{voltage}$$

he calculated voltage to which this condenser would be charged. Again using equation of equal charge on the capacitance c and on the Earth (considered to be a ball of capacitance C) he calculates potential on the earth as $p = \frac{c}{C} P$, again not considering frequency! When frequency is taken into account he assumes wavelength to be λ , and calculates voltage across the equatorial belt of area $\pi D \lambda / 2$.

With overall results he is not satisfied and at the end he concludes that "This can not be true."

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